Lower Laguna Madre/ Brownsville Ship Channel Watershed Characterization 2018

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1 INTRODUCTION

1.1 PROJECT SUMMARY

The Lower Laguna Madre/Brownsville Ship Channel (LLM/BSC) watershed is the area south of the Arroyo Colorado watershed and north of the Rio Grande watershed. It is fully within Cameron County and includes the cites of Brownsville, Port Isabel, South Padre, Laguna Vista, Bayview, Los Fresnos, Rancho Viejo, and La Paloma. This watershed has a population of approximately 350,000 and is expected to increase over the next 20 years (citation required….). The watershed is part of the Rio Grande delta but its hydrologic connection to the Rio Grande River has been highly modified due to artificial impoundments of the Rio Grande River upstream of the watershed for flooding and irrigation purposes. The Rio Grande River has natural levees which form the southern boundary of the LLM/BSC watershed and the northern boundary of the Rio Grande watershed. The natural drainage of the watershed has been highly modified by the excavating of the Brownsville Ship Channel, development of a drainage ditch network, and redistribution of water from the Rio Grande River via canals and resacas for irrigation purposes. Significant land uses in the watershed include wetlands, urban, crop and pasture land.

The watershed includes several TCEQ segments (Figure 1-1): Brownsville Ship Channel (2494), Port Isabel Fishing Harbor (2494A), Main drainage ditches flowing into 2494(2494B_01), Minor drainage ditches flowing into 2494, San Martin Lakes (2494C), minor drainage ditches draining directly to the Lower Laguna Madre (2491C), and South Bay (2493). According to the Draft 2016 Texas Integrated Report, the Brownsville Ship Channel and Port Isabel Fishing Harbor are currently listed as having bacteria impairments. The Lower Laguna Madre assessment unit (AU) 2491_03 has concerns for low dissolved oxygen and high bacteria levels. The Lower Laguna Madre AU 2491_02 directly north of the area that the Arroyo Colorado flows into is impaired for low DO and bacteria.

The drainage network of the watershed flows into three main receiving water bodies: 1) San Martin Lake, 2) Brownsville Ship Channel, and 3) Lower Laguna Madre. Two of the three main drains flow into San Martin Lake system and then into the Ship Channel. The 3rd main drain, comprised of runoff from the downtown and Southmost areas of Brownsville, flows directly into the southwestern end of the Brownsville Ship Channel. The Ship Channel is hydraulically connected to the Lower Laguna Madre near Port Isabel and the southern end of South Padre Island. A freshwater inflow modeling effort conducted in 2012 showed that between 15-25% of surface runoff inflows come from the LLM/BSC watershed (BBEST, 2012). Bahia Grande and South Bay receive limited overland drainage but do receive tidal inflows from Lower Laguna Madre and the Brownsville Ship Channel. Resacas, ancient distributary channels of the Rio Grande River, are numerous in the watershed and are important for wildlife habitat, recreation, flood protection, water supply storage, and irrigation. Resacas receive some drainage runoff and many are used as a distribution network for Rio Grande water for irrigation and other water uses. However, they generally only contribute to the drainage network during high flow events, with the exception of Town Resaca.

Very limited data has been collected to assess instream water quality in the watershed. There is notably a lack of detailed water quality information on San Martin Lake, the various drainage networks, and resacas; however, there are growing efforts by stakeholders (researchers, local government, and citizen scientists) to more closely monitor these important water resources.

The main goals of this project were to 1) Establish a local watershed stakeholder group, 2) identify and assess existing water quality related information, 3) identify data gaps, 4) gather existing geospatial information into a geodatabase and maps, 5) collect and develop new information as funding allowed, and 6) write this watershed characterization report

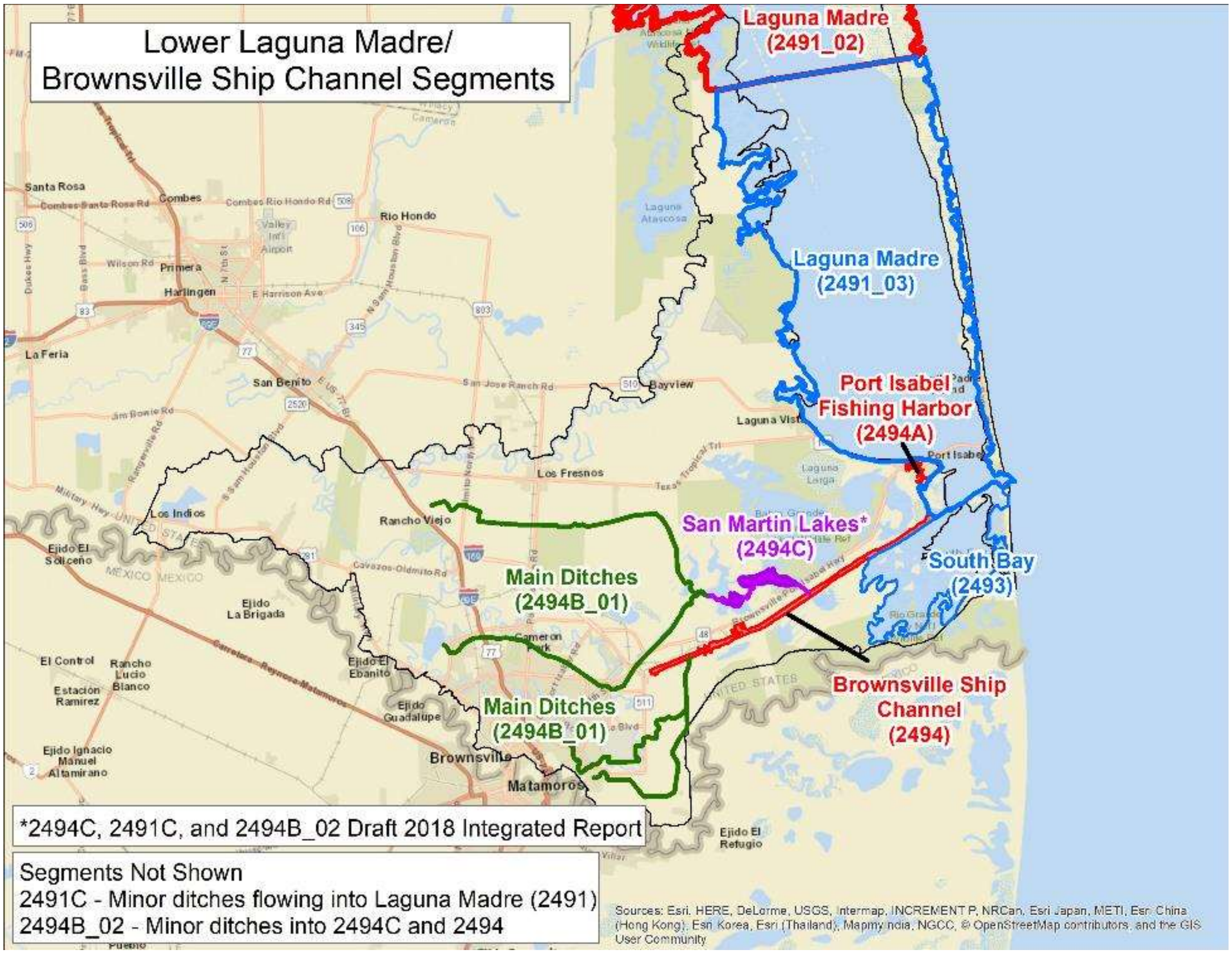


Figure 1-1. TCEQ Segments Lower Laguna Madre (2491) and Brownsville Ship Channel (2494) and tributary segments.

1.2 GEOGRAPHY AND CLIMATE

Located entirely within Cameron County, Texas, the LLM/BSC watershed drains the southeastern-most landscape in the state (Figure 1-2). Low relief, sandy-clayey soils, hot summers and ample year-round sunshine strongly define this coastal sub-tropical region. The average annual precipitation is slightly more than 27 in. and over a third of it (10 in.) usually arrives during mid-August through October, when water temperatures in the Gulf of Mexico are peaked and tropical storms are more common (Figure 1-3). Evapotranspiration rates are typically 2 – 3 times greater than precipitation.

Figure 1-2. Boundary of the Lower Laguna Madre / Brownsville Ship Channel watershed.

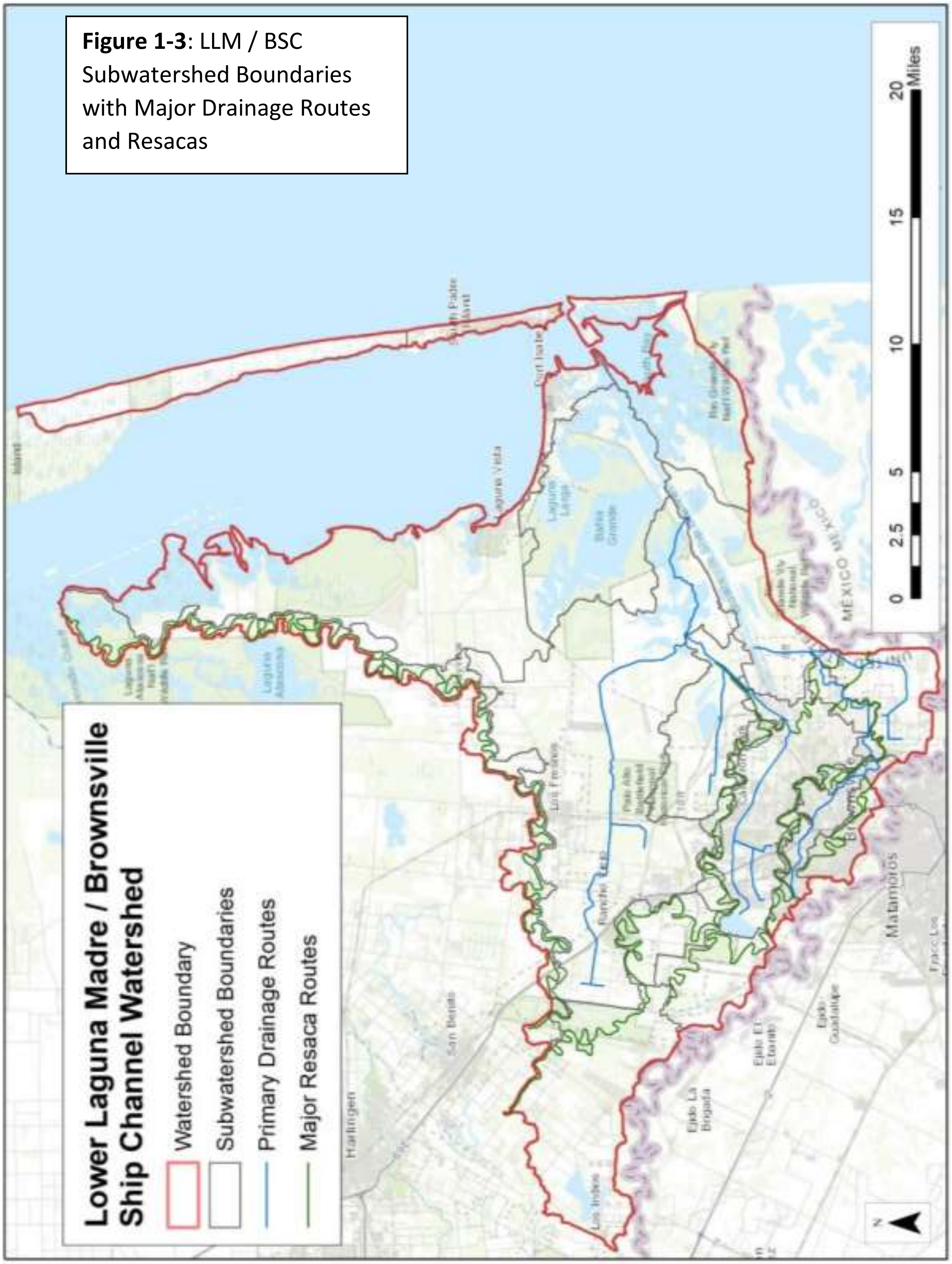


Figure 1-3: LLM / BSC Subwatershed Boundaries with Major Drainage Routes and Resacas

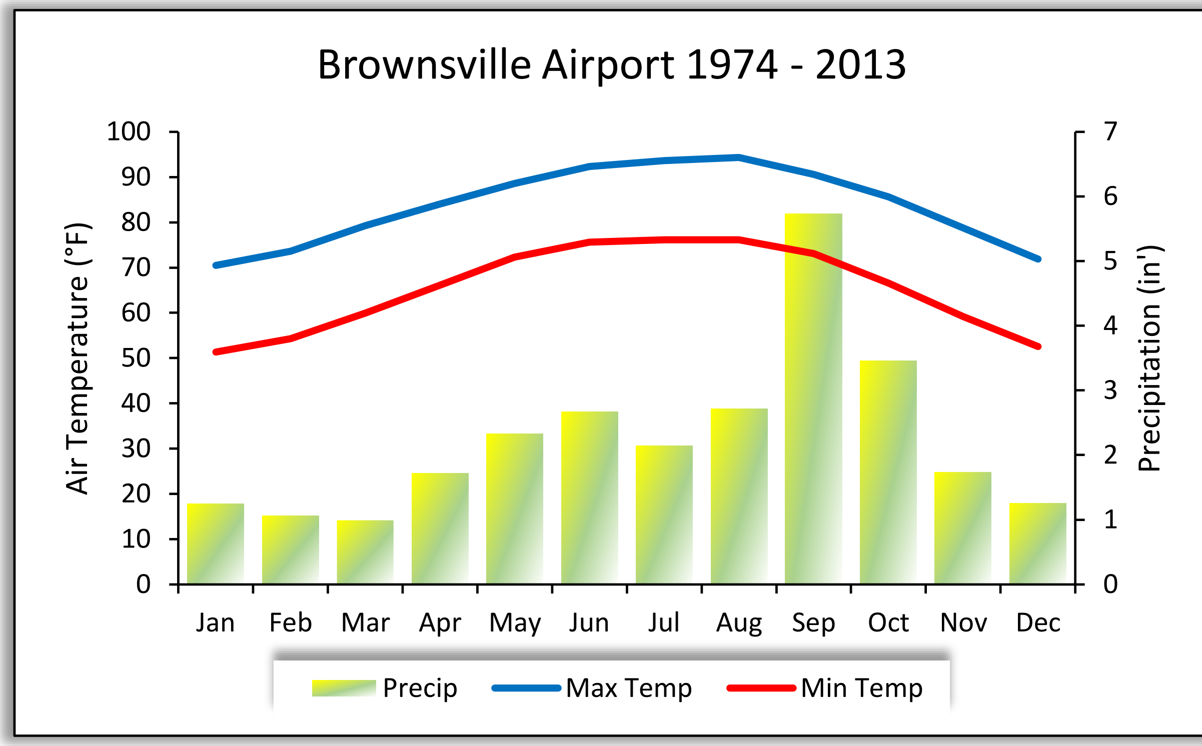


Figure 1-4. Average monthly air temperature and precipitation at Brownsville Airport, Texas, 1974–2013. Source: NCDC (2015).

1.3 General Hydrography

Resacas define the western hydrography of the LLM / BSC watershed. Resacas are natural, intermittently-flowing, meandering distributaries of the Rio Grande River. Distributaries are the opposite hydrographic feature to a tributary and often form within the deltas of rivers depending on a variety of other conditions. These distributary features that formed over thousands of years, formed channels that would aid in the dissipating of Rio Grande floodwaters. Over time, distributaries often naturally become hydraulically disconnected from their source river through the source river's own development of natural levees. The alteration of natural flood flows in the Rio Grande River delta due to anthropogenic activities such as the creation of dams, artificial levees, and intensive water withdrawals, have also aided in diminished flood flows into these ancient systems. Nevertheless, agricultural demand for irrigation water in the 20th century has permitted these abandoned distributaries to somewhat mimic the historical flood cycle (albeit to a much smaller degree). Some resaca systems (like Town Resaca), whose subwatersheds are heavily urbanized, have been engineered for the conveyance of stormwater from the Brownsville area to the Brownsville Ship Channel – more closely fulfilling the role of a drainage mechanism than other resaca systems. It is challenging to strictly define the hydrography of the resaca system in the Brownsville area because flow connections between upstream and downstream reaches include both natural and engineered elements. Flow is intermittent, often driven by precipitation but also controlled at times by pumping for irrigation and other purposes. Resacas in rural areas are less heavily dominated by stormwater conveyance and are more often either supply water storage and conveyance mechanisms, or if not augmented with pumped water from the river, resemble marshes rather than lakes or flowing streams. The largest resacas meander southeasterly through different latitudes of the watershed. The northernmost resaca of this watershed, Resaca de los Cuates (RC), represents the northern boundary of the watershed (Figure 1-2). To the south of RDLC is the Resaca del Rancho Viejo (RRV) that serves a dual purpose of water storage / conveyance and limited stormwater conveyance. Resaca de la Guerra (RG) / Resaca de la Palma (RP) is found south of the RRV and is more urbanized, with an increasing role of water supply conveyance and increasing stormwater conveyance for subdivisions and urbanized pockets of land near its banks. (Note: Both RG and RP are common names for this resaca system; however, RP is the official name on USGS maps.) Flowing through the heart of Brownsville is Town Resaca (TR), which has its levels maintained by pumped river water like RG / RP, but primarily serves a vital stormwater drainange role for downtown Brownsville

Several major drainage ditches maintained by the Cameron County Drainage District, the City of Brownsville, and the Brownsville Irrigation District convey stormwater, irrigation return flows, and wastewater from the northwest, west, and southwest of the watershed into San Martin Lake and the Ship Channel (Figure 1-4). These include Cameron County Drainage Ditch #1 (CCDD#1), North Main Drain (NMD), and Main Ditch #2 (MD#2). Flow direction is driven by the combined influences of low topographic relief, limited days of significant precipitation, irrigation pumping, and strong winds, especially when tropical systems in the Gulf press inland.

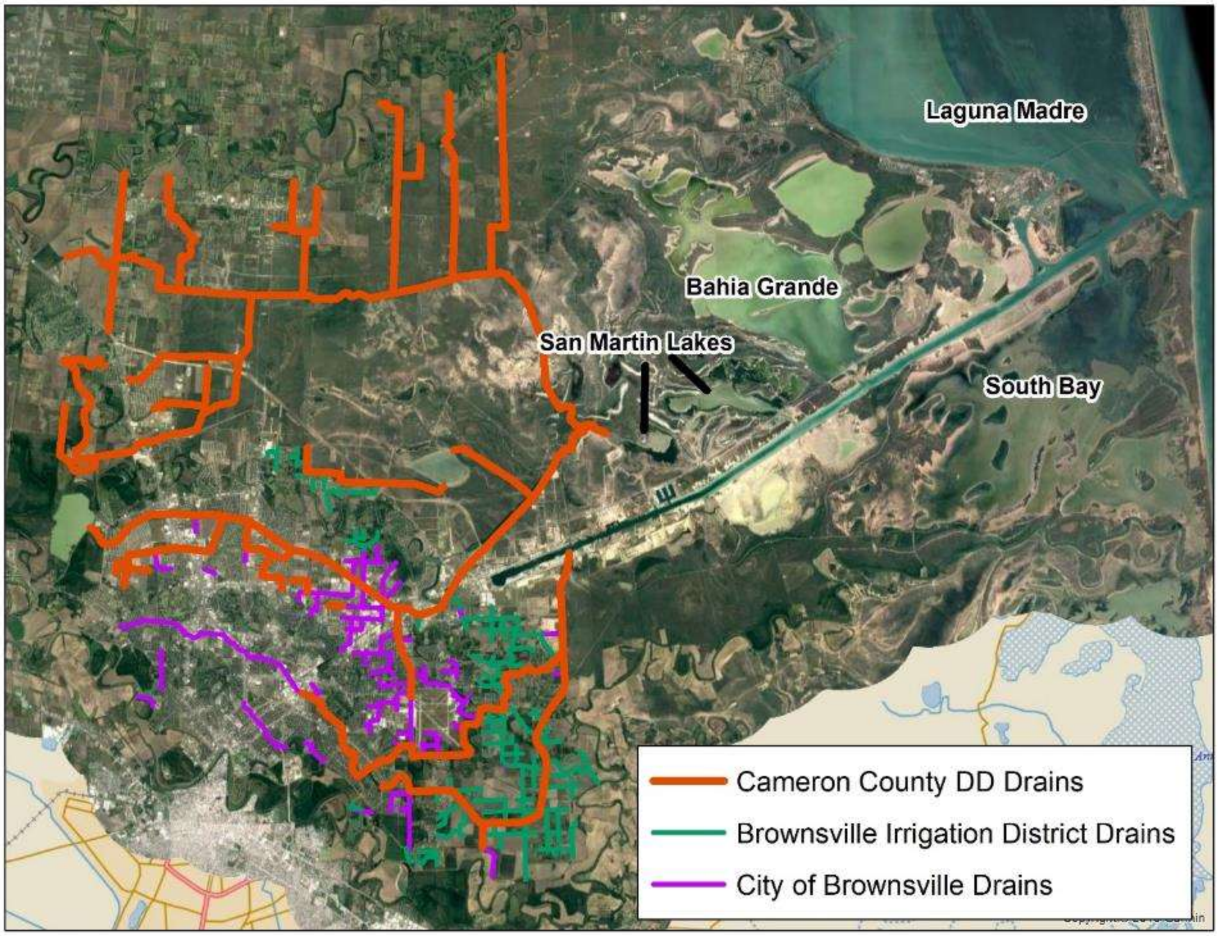


Figure 1-5. Major drains conveying stormwater, irrigation return flows, and wastewater to Ship Channel and San Martin Lake.

1.4 EcoRegions and Habitat

The drainage network of the watershed flows into three main receiving water bodies: 1) San Martin Lake, 2) Brownsville Ship Channel, and 3) Lower Laguna Madre. San Martin Lake and Little San Martin Lake are waterbodies that receive urban runoff, agriculture runoff, and wastewater effluent by way of 2 of the main 3 drains of the Brownsville Ship Channel watershed. San Martin Lake is designated a paddling trail and there is frequent kayak fishing and potentially wade fishing. A study funded by the Coastal Management Program (http://www.glo.texas.gov/coastal-grants/_documents/grant-project/14-085-final-rpt.pdf) showed high nitrate concentrations during storm events just upstream of Little San Martin Lake. It is unknown how much freshwater makes it out of the lake system into the Ship Channel. The water quality in the Ship Channel at the outlet of San Martin Lake does not show lower salinities or higher pollutant concentrations indicating freshwater inflow. The 3rd main drain, comprised of two resaca systems and two drains (North Main and Southmost), flows directly into the Brownsville Ship Channel. The Ship Channel flows into the Lower Laguna Madre. A freshwater inflow modeling effort conducted in 2012 showed that between 15-25% of surface runoff inflows comes from the LLM / BSC

(BBEST, 2012). Bahia Grande and South Bay receive limited overland drainage but do receive tidal inflows from Lower Laguna Madre and the Brownsville Ship Channel.

The western half of the watershed, encompassing the majority of the urban landscape in the watershed, is located in the Lower Rio Grande Alluvial Floodplain (TCEQ, 2007) where alluvial sands and clays dominate. The mostly Vertisol and Mollisol soils support cotton, citrus, and grain sorghum among other vegetables and fruits in the rural districts. Nearly all of this ecoregion has been heavily modified by agriculture and urban development, however, a few parcels of rare old forest species remain including Texas ebony (*Pithecellobium flexicaule*), Texas palmetto (*Sabal mexicana*), and sugar hackberry-cedar elm (*Celtis laevigata-Ulmus crassifolia*) still can be found. Suburban development has been predominately northward and northwestward from development associated with the growth of Brownsville. Urbanization of once agricultural land and fallow land is now common and is shifting the non-point source runoff water quality spectrum from agricultural to urban type pollutants. This is particularly true for resaca systems that are being called to serve an increasing stormwater conveyance role as urbanization moves northward.

The eastern half of the watershed is within the Laguna Madre Barrier Islands and Coastal Marshes. Hypersaline lagoons, marshes, lomas, and muddy tidal flats are the dominant elements of the mainland Gulf tip of Texas and provide important coastal habitat for wildlife. The Laguna Atascosa National Wildlife Refuge protects much of this habitat. The BSC flows through the middle of this ecoregion and except for the immediate industrial corridor it is surrounded on the north and south by largely undeveloped dunes and lagoons. Thousands of acres of these lagoon beds are intermittently inundated depending on tides and precipitation. The dunes that rise out of the lagoons and along the spine of SPI represent the most topographic features in the watershed, though elevations of the tallest dunes range only 20 – 30 feet. The south end of SPI is heavily developed with residential, commercial, and industrial structures. The wilderness of the north end of the Island is a stark contrast to the urban south. Native vegetation, and mostly undisturbed dunes are prime habitat for a diversity of animals including migratory birds.

The Laguna Madre is one of only five known hypersaline estuary systems in the world (The Nature Conservancy, 2016) and the basis of the Laguna Madre food web is shoal grass (*Halodule wrightii*) meadows that account for roughly 80% of the seagrass beds in Texas. The seagrass meadows support a large diversity of fish, sea turtles, water waterfowl, including the redhead duck (*Aythya americana*). Much of the land surrounding the Lower Laguna Madre is protected habitat.

USFWS National Wildlife Refuge System is a national network of lands and waters set aside for the benefit of wildlife and people. The USFWS works with willing landowners to purchase tracts of land or conservation easements within the approved acquisition boundaries of the refuge. The LRGV is home to three USFWS National Wildlife Refuges: the Lower Rio Grande Valley, the Laguna Atascosa and the Santa Ana National Wildlife refuges.

The Laguna Atascosa Refuge was established in 1946 to provide habitat for wintering waterfowl and other migratory birds, principally redhead ducks. Since establishment, focus has expanded to include endangered species conservation and management for shorebirds. The refuge is a premiere bird-watching destination and includes more recorded bird species than any other refuge in the National Wildlife Refuge System. The refuge is also home to the largest population of ocelots in the U.S. The refuge's approved acquisition boundary includes a large area along the coast.

In 2000, the Laguna Atascosa National Wildlife Refuge acquired the 21,700 acre Bahia Grande Unit which is fully located within the LLM/BSC Watershed. Bahia Grande, "Big Bay", was once a large and productive wetland that was connected to the Lower Laguna Madre system. The natural tidal flow between the Bahia Grande and the Laguna Madre was cut off by construction of the Brownsville Ship Channel in around 1950. For years the dry Bahia Grande was a source of blowing dust in the area. In 2005, tidal flow to the Bahia Grande was restored via a pilot channel dug from the Brownsville Ship Channel. The Bahia Grande is considered one of the largest and most successful coastal wetland restoration projects in the United States. Further work is planned to widen the pilot channel. (citation required)

The dredging of the Brownsville Ship Channel also altered flow of another important coastal water body in the watershed named San Martin Lake. San Martin Lake used to be a large lake as shown in 1920s topographic map (citation required) prior to dredging of Brownsville Ship Channel. San Martin Lake and Little San Martin Lake make up a small portion of the lake that is still perennially wet. San Martin Lake system serves as an estuary habitat. It receives freshwater flow from 2 of the main 3 ditches in the LLM/BSC watershed, and is connected to the Ship Channel and saltwater flows into the Lake daily.

The many resacas in the watershed, regardless of the degree of modification, provide habitat for a large variety of wetland plants and animals, including waterfowl, beaver, nutria, alligators and a host of other reptiles and amphibians. The resacas may also provide microclimate effects in and around the LLM / BSC area; however, this effect has not been scientifically verified and remains anecdotal in nature only.

Figure 1-6. 1920s topography map with modern Ship Channel and San Martin boundaries overlain.

1.5 RESACAS AND THEIR INFLUENCE ON WATERSHED DRAINAGE PATTERNS

The word “resaca” is a colloquial term for a large system of old, hydrologically abandoned, distributaries of the Rio Grande River. These distributary features are present in various hydrologic and ecological conditions across its entire delta. The vast majority of the thousands of miles of historical pathways that the Rio Grande River periodically inundated during times of high streamflow are now barely noticeable to the untrained eye. In most cases, these older systems are only discernible by looking at detailed geologic maps, identifying portions of their historical pathways in aerial photography, or seeing remnant surface depressions in high-resolution topographic datasets like LiDAR.

Rivers often abandon their distributaries throughout their geologic history due to a variety of natural causes such as meandering, sudden bank shifts, redirections of river flow due to flow restriction or blockages caused by sediment or other material, etc. This process usually occurs slowly over hundreds to thousands of years; however, it can be expedited by anthropogenic causes such as: water withdrawals for irrigation, demand for municipal uses, and even flood protection mechanisms like dams, artificial levees and diversion channels. In fact, the Rio Grande Federal Flood Control Project’s system of dams, levees and diversion channels, combined with the intense and ever-growing water demands placed on the river by anthropogenic uses, have essentially locked-in-place the current distributary network as it is seen today. The Rio Grande River’s downstream flows are controlled to such a point that any further changes to the distributary network are unlikely – barring a catastrophic natural disaster or failure of the established infrastructure. Figure 1-6 shows a rough estimation of the ancient distributary network formed by the Rio Grande River delta.

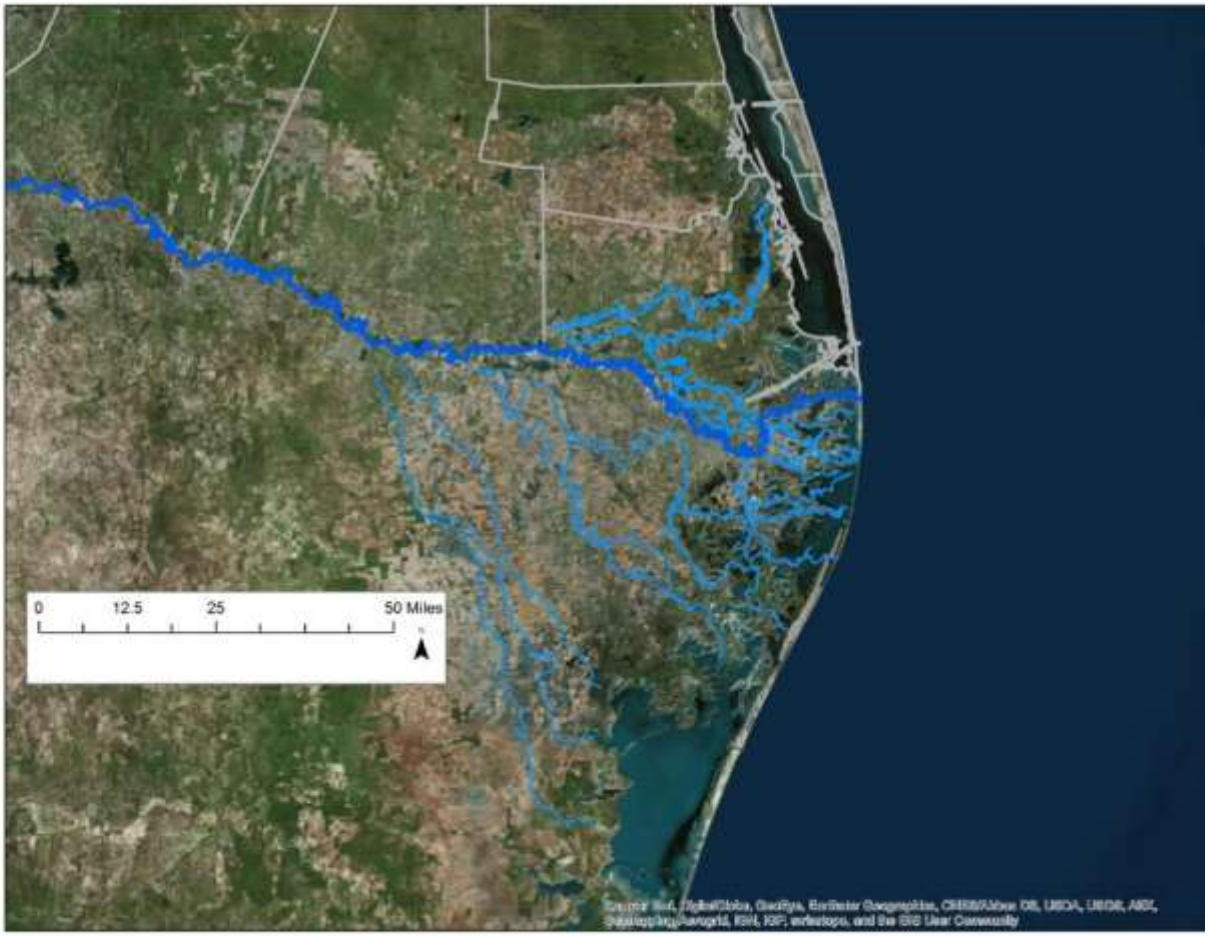


Figure 1-7. Estimation of the Distributary Network of the Rio Grande River across its Delta. The blue lines represent distributary features that are either normally inundated, partially inundated / dry, wetland, or primarily dry. The thicker blue line represents the present day flow path for the Rio Grande River proper.

1.5.1 Latitudinal Flow Characteristics of Resacas

Latitudinal flow in a river system is defined as flow that is lateral or perpendicular to the primary upstream / downstream direction of the river system. It is essential to understand the role that each resacas system of elevated, natural levees plays in restricting lateral inflows of stomwater runoff into the systems themselves.

Each resaca system has a broad, natural levee system that is viewable in topographic maps, in particular, LiDAR high-resolution topography. Figure 1-7 shows the elevated and broad natural levees that resulted from the depositional processes of the distributaries. The levees associated with and formed by each resaca system are higher than the surrounding areas and as a result, completely define the drainage patterns of the LLM / BSC by restricting much of the latitudinal flow into resacas. In other words, the natural levees result in subwatershed boundaries that are located very close to the resaca system. As a further consequence, resacas DO NOT drain much of the surrounding area and drainage ditches are required to drain the lower elevation land areas found between the resaca systems.

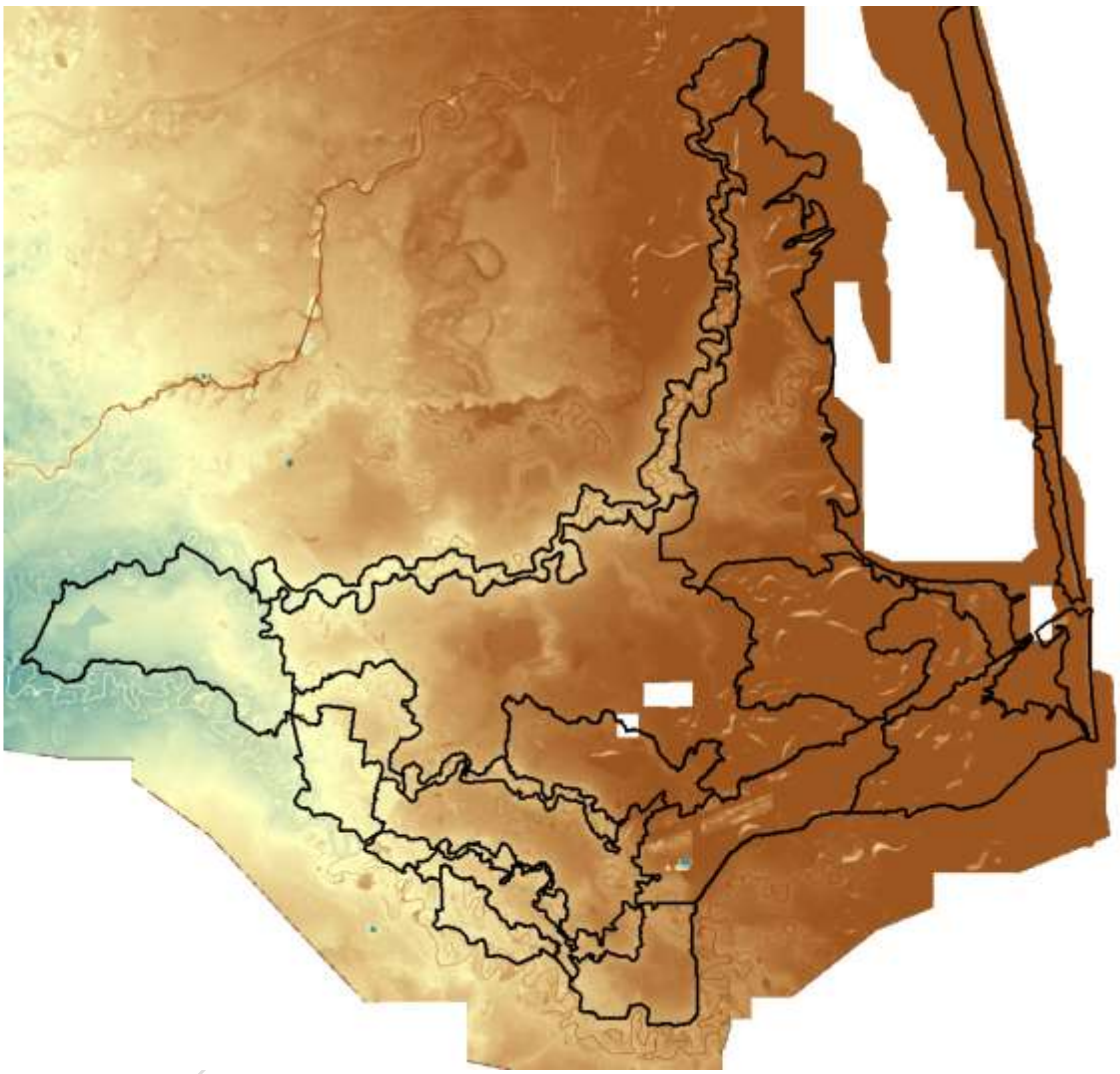


Figure 1-8. LiDAR Image of the LLM / BSC watershed area. Elevations range from 45 feet (light blue) to light yellow (15-25 feet) to brown / orange (0-15 feet). Note the higher, natural levees associated with the resaca systems and the low lying interstitial areas between the resacas. (Need to include a legend)

Figures 1-8and 1-9are shown here in order to make sure that the reader clearly understands the terms "natural levee" and the important, significant difference between "ox-bows" and "distributaries."

1.5.2 Longitudinal Flow Characteristics of Resacas

Longitudinal flow in a river system is defined as flow in the normal, downstream direction of a river's path. It is important to understand how the longitudinal flow patterns of resaca systems have been altered by both natural and anthropogenic causes.

As discussed earlier, resacas are naturally abandoned distributaries of the Rio Grande River. This "isolation from natural flows" is due to factors also previously discussed: damming of upstream flood flows, large water withdrawals for municipal and agricultural uses, and the formation of the Rio Grande River's own natural levees. Resacas also generally flow in an eastward direction toward the Gulf of Mexico and mean sea level. Additionally, development across the Rio Grande River delta and the LLM / BSC watershed has resulted in each of the resaca systems being crossed over by roads, bridges, railroads, and other infrastructure at numerous points along their longitudinal direction. This all combines to make resaca systems function more like a system of linear, level-pool lakes or ponds that are often, but not always, hydraulically connected along their longitudinal direction via culverts, pipes, overflow boxes or other such flow and level control devices.

In many cases, infrastructure that has crossed the resaca path, such as a road, railroad, etc., includes some sort of hydraulic structure like a box culvert, concrete pipe, or overflow box to permit flow or overflow to the next downstream pool or pond. Figure 1-10 is an example of the GIS database being established for this watershed. The snapshot shows where hydraulic structures are located along the historic, longitudinal direction of flow of three resaca systems in the LLM / BSC area: Rancho Viejo, Resaca de la Palma, and Town Resaca. The most important structures in these systems are those structures that function as level-control devices such as weirs and overflow boxes. These particular structures regulate the water level in the pools upstream of their specific location and, during periods of low-flow, may significantly increase the hydraulic residence time of water in these pools. Figure 1-11 shows a simplified schematic of a profile view of a sample resaca section along with example weirs, road crossing, box-culvert and reinforced concrete pipe connections. The system of weirs along these resaca systems are essential to maintain water levels appropriate to the nearby bank elevations.

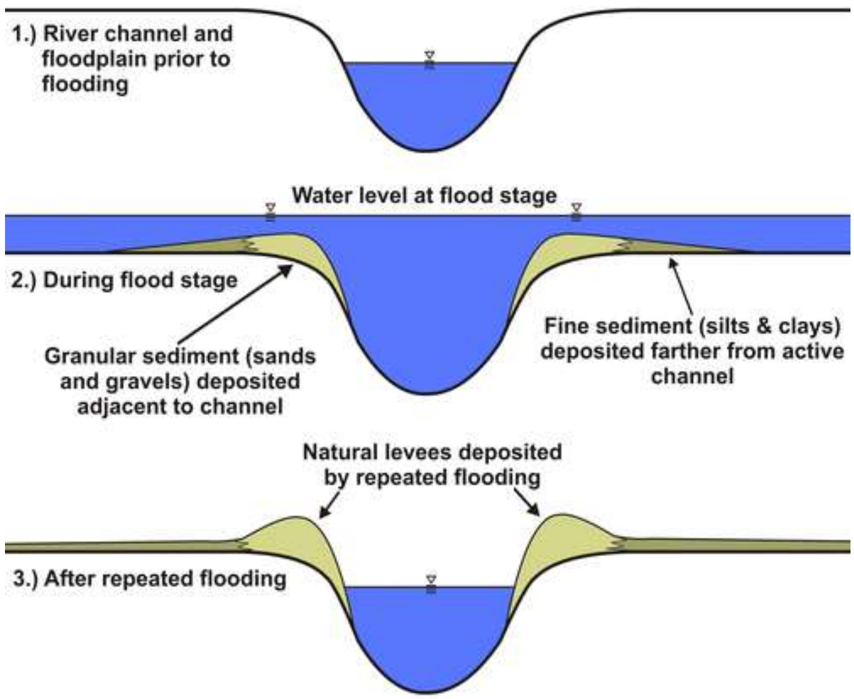
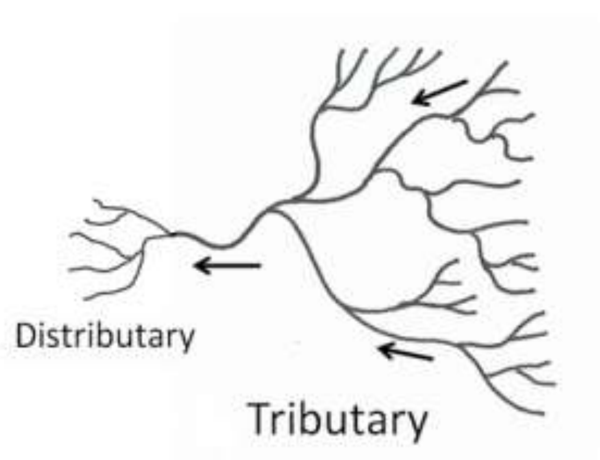


Figure 1-9. Illustration showing how natural levees form around the banks of distributaries, rivers, and other waterways that are depositional in nature or part of a delta distributary system. The elevated, natural levee area prevents significant stormwater runoff from entering the channels with the exception of cases where the levee is underpassed by a storm sewer or the rainfall event is significant.



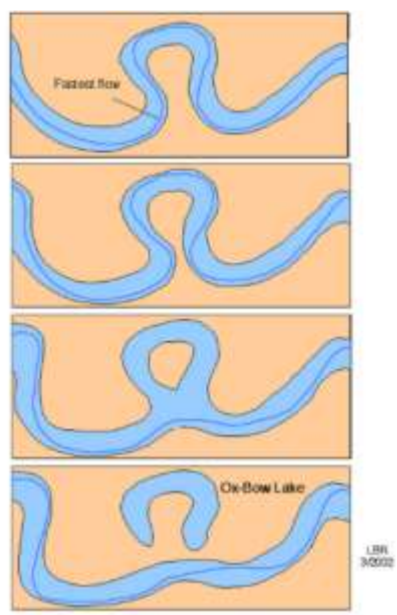


Figure 1-10. Illustration showing the drastically different formation processes behind distributaries (left) and ox-bows (right).

Figure 1-11. Snapshot of a sample set of layers from the LLM / BSC GIS Databased being developed as part of this project. This image shows the approximate locations of hydraulic features located in three of the Brownsville area resacas as well as the interstitial low-lying drainage ditches between them. (https://amnovak.github.io/resaca-explorer/)

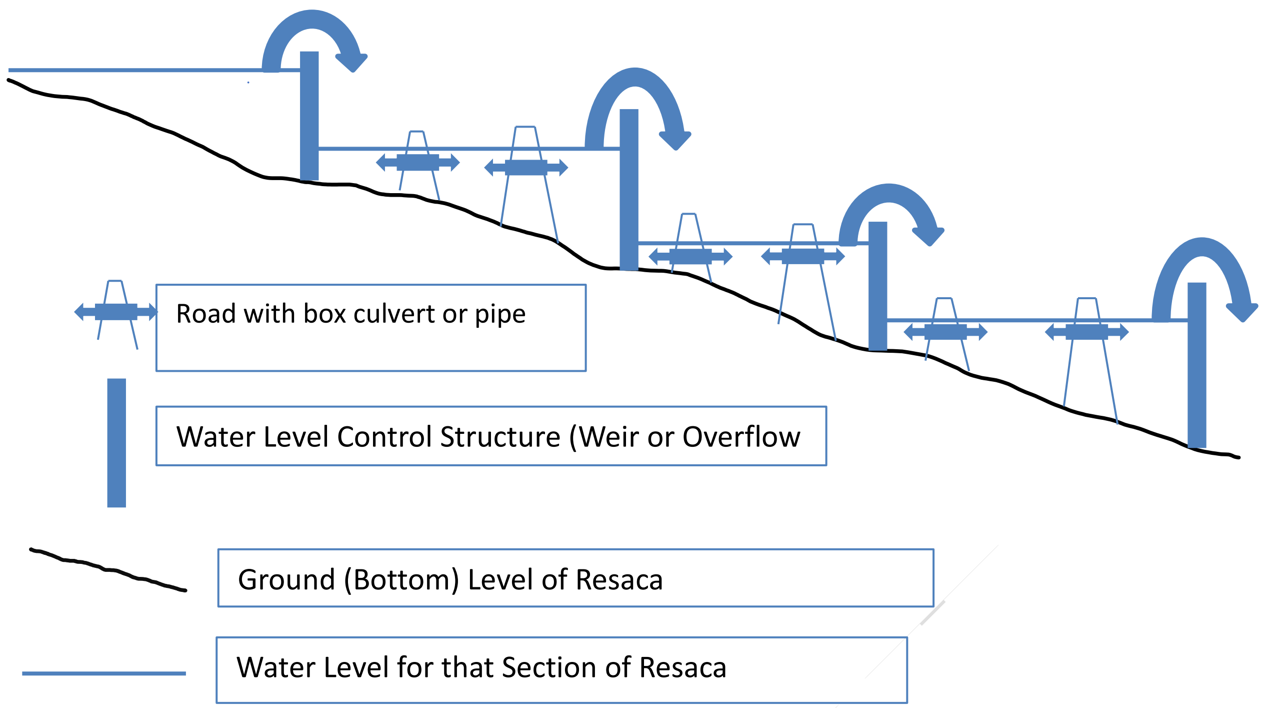


Figure 1-12. Simplified Schematic showing how individual pools or lakes within a single resaca system are hydraulically connected via box culvert or drain pipe as well as how weirs (low dams) control the upstream section's water level out of necessity (due to topographic gradient shown by black line).

2 Subwatershed Delineations and Land Use

The overall LLM / BSC watershed boundary and its respective subwatershed boundaries were delineated using:

- high-resolution light detection and ranging (LiDAR) topographic data,

- the National Hydrography Dataset Plus Version 2 flowlines (NHD Plus v2),

- satellite and aerial imagery,

- previous delineations from existing flood studies,

- local knowledge from utility, irrigation, and drainage districts,

- and limited ground-truthing of some of the more topographically complex areas (typically coinciding with areas of confluence and / or divergence of subwatershed topographic boundaries, irrigation canals, drainage ditches and resacas.

The subwatersheds represent hydrologic units within the total study area that do not necessarily correspond to TCEQ Assessment Unit (AU) watersheds or Hydrologic Unit Code (HUC) boundaries, nor do they align perfectly with NHD Plus v2 catchments. Deviations from these delineation efforts were done to more accurately reflect drainage patterns and to more accurately assess potential contaminant flow paths and the identification / location of potential sources of pollution.

The delineation of subwatershed boundaries in relatively flat areas is an enormously difficult and complex task. The boundaries shown in this report are not to be considered final; however, they do represent the culmination of years of work sourced from various experts, reports, and high-resolution data. An important note for the reader to understand is that the traditional eight- direction flow model (D8), as well as other flow direction algorithms using GIS and DEMs (D16, D32, D-infinity, etc.), traditionally perform poorly in watersheds such as this one due to low elevation gradients and the effects of various types of infrastructure on flow patterns. This is particularly true when flow patterns resulting from low-intensity rainfall events are of great interest – as is often the case when water quality is the concern. For these reasons, the overall watershed / subwatersheds boundary delineation method used a combination of the above listed data sources instead of relying solely on computer-generated (GIS / DEM) boundaries.

2.1 Subwatershed Overview

The Lower Laguna Madre / Brownsville Ship Channel watershed was subdivided into 15 subwatersheds (Figure 2-1). These subwatersheds were identified from various factors including:

- drainage pattern,
- drainage density,
- outfall location,
- landuse patterns,
- population density,
- location (coastal vs. inland),
- conveyance mechanism (resaca / drainage ditch / overland flow),

- and most importantly, whether delineating that particular subwatershed would simplify water quality monitoring and source location identification.

Four of the fifteen subwatersheds were further subdivided into subsections. This occurred when a noticeable change in one or more of the above listed factors differed substantially across the subwatershed, but the area as a whole still drained to a common point through the same conveyance mechanism (Resaca de los Cuates, Resaca del Rancho Viejo, and Resaca de la Palma / Guerra) or were part of a well-defined geographic feature (South Padre Island).

2.1.1 Overall LLM / BSC Basin

The LLM /BSC watershed is relatively unique in that it does not have a single, primary drainage conduit and outlet. Figure 2-2 shows the overall watershed's National Land Cover Dataset data along with basin boundaries and primary waterways (drainage ditches, resacas, ship channel, and bays). The BSC (a man-made feature) serves as the primary runoff collection feature for approximately 75 % of the entire LLM / BSC basin. It collects the runoff from two separate major drainage ditch networks. The Northern drainage network drains to the tidally influenced San Martin Lake (SML) system where it mixes with saltwater. SML is connected to the BSC via a narrow channel where water flows back and forth between the BSC and SML daily. The Southern drainage network drains directly into the BSC. The BSC receives additional direct overland flow from areas not part of these two drainage networks. The BSC is a tidally influenced feature that is hydraulically connected to the LLM near the channel's eastward terminus and is connected to the Gulf of Mexico through the Brazos Santiago Pass between South Padre Island and Boca Chica Beach. The coastal subwatersheds of the LLM / BSC basin drain directly to either the LLM, GOM, or the BSC via direct overland flow without the presence of a well-defined drainage feature such as a stream, arroyo, channel or ditch.

The following section of this report provides specific information on each of the subwatersheds.

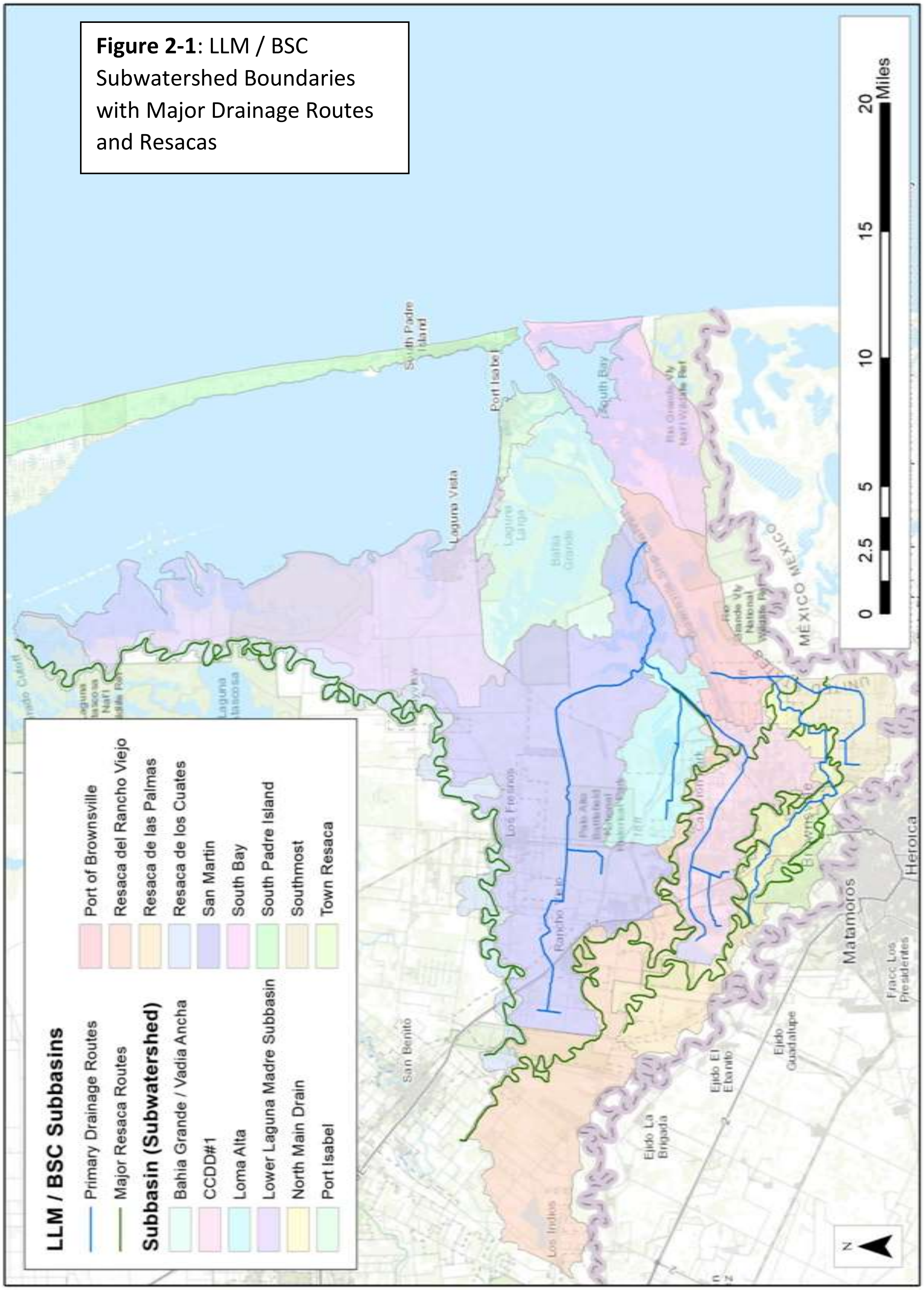


Figure 2-1: LLM / BSC Subwatershed Boundaries with Major Drainage Routes and Resacas

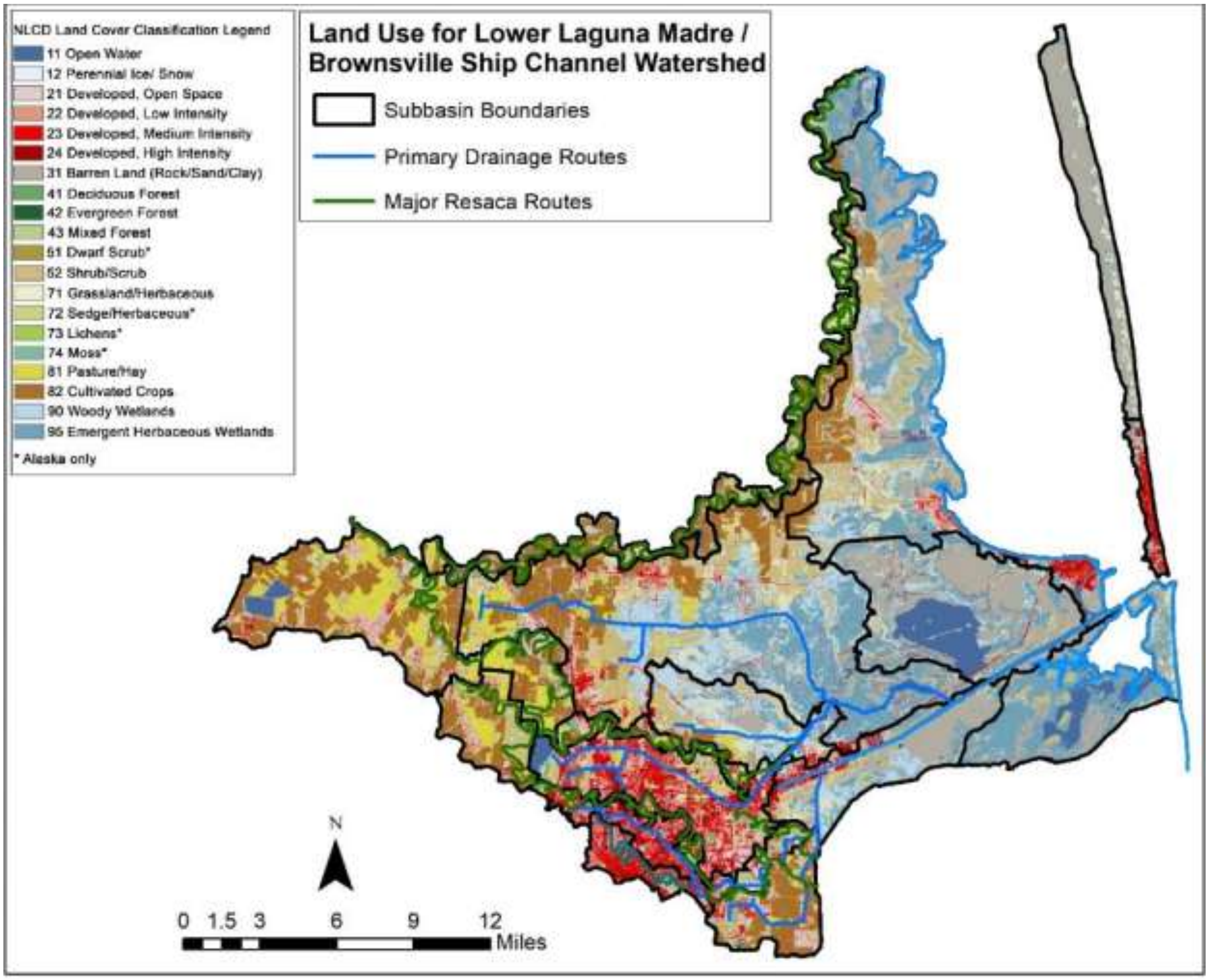


Figure 2-2. National Land Cover Data (2011) for the various Subwatersheds in the LLM / BSC Watershed

2.1.2 Subwatershed Types – Characterization based on hydrologic conveyance.

The LLM / BSC watershed's 15 basins are comprised of three different types of subwatersheds as defined by their method of conveyance of rainfall runoff and their low-flow condition of hydrologic "sink" or drainage basin (Figures 2-1 and 2-3).

- <u>Primary Drainage Basins</u>: traditional drainage basins are characterized by overland flow to a channel network that flows to a main drainage feature with a well-defined, single outlet. These include (in order of north to south):
    - County Cameron Drainage Ditch #2 (San Martin Lake Drain).
    - Cameron County Drainage Ditch #1;
    - Loma Alta Subwatershed;

- North Main Drain;
- Southmost Drain;

- Coastal Basins: coastal basins are characterized by overland flow with or without a channel network, but without a main drainage feature and with no well-defined, single outlet. These include:

    - Port of Brownsville Subwatershed;
    - Bahia Grande / Vadia Ancha Subwatershed;
    - South Bay Subwatershed;
    - Lower Laguna Madre Subwatershed;
    - Port Isabel Subwatershed;
    - South Padre Island Subwatershed (north and south subsections).

- Resaca Basins: these basins are defined by a network of abandoned distributaries of the Rio Grande (Resacas). Their boundaries are mostly determined by the natural levees created by these features as part of the Rio Grande delta distributary (see Figure 1-6). These systems do not convey flood-waters as free flowing systems, but instead operate more as a series of connected level-pool reservoirs regulated by downstream water level structures such as standpipes, overflow boxes, and / or weirs. Some runoff from storm sewer networks (neighborhood scale) can be present in these systems; however, storm sewers are not a dominant component of total runoff and/or conveyance in these types of resaca systems. Some of the subsections of these basins may not connect hydrologically at all to the more downstream subsections and as such, may be considered hydrologic "sinks" with respect to runoff and drainage. Portions of these systems are also used for the storage and transport of irrigation water for agriculture and landscaping. The resaca subwatersheds include (in order of North to South):

    - Resaca de los Cuates Subwatershed
        - Upstream section. Either a sink or a drainage system depending on duration and intensity of rainfall event.
        - Downstream section. Most likely a sink with significant coastal effects during periods of high tide and even the smallest of storm surge events.
    - Resaca del Rancho Viejo Subwatershed
        - Upstream section. Most likely a sink.
        - Midstream section. Most likely a sink. Serves as a water storage and conveyance mechanism for agricultural and municipal use.
        - Downstream section. Either a sink or a drainage system depending on duration and intensity of rainfall event. Portions serve as a water storage and conveyance mechanism for agricultural and municipal use.
    - Resaca de la Guerra / Palma Subwatershed
        - Upstream section. Most likely a sink.
        - Downstream section. Either a sink or a drainage system depending on duration and intensity of rainfall event. Serves as a water storage and conveyance mechanism for agricultural and municipal use. This system is dominated by pumped pass-through water by the Brownsville Public Utilities Board for the purpose of conveying municipal and landscape irrigation water.

- <u>Stormwater Dominated Resaca Basin</u>: similar to other Resaca basins except that the basin boundary is primarily defined by a large, urban storm sewer network.
    - Town Resaca Subwatershed
        - This system (only one present) is dominated by pumped pass-through / augment water by the Brownsville Public Utilities Board. The system serves as the primary stormwater / floodwater conveyance mechanism for almost all of downtown Brownsville. It also serves as storage and conveyance of landscape irrigation water.

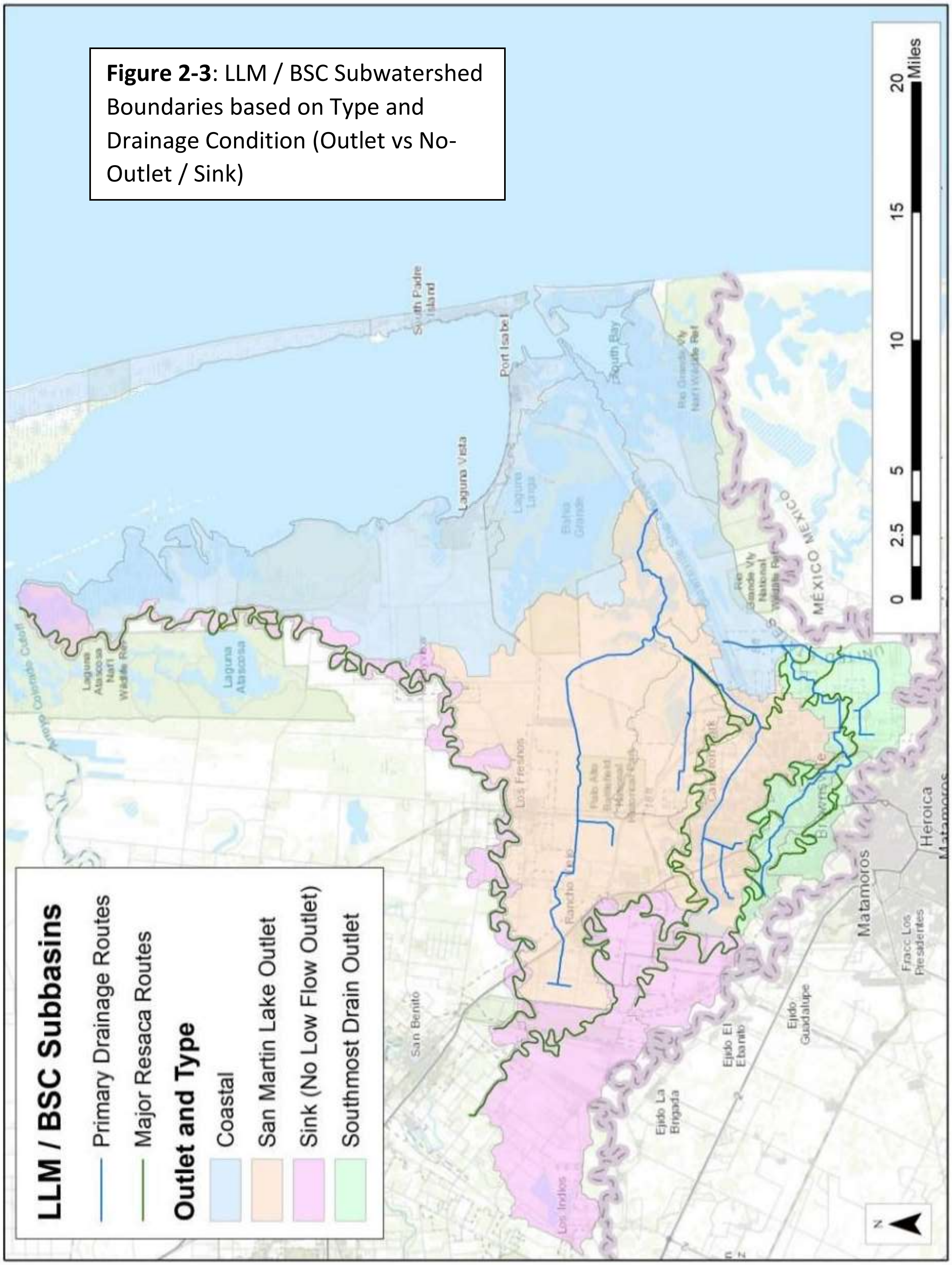


Figure 2-3: LLM / BSC Subwatershed Boundaries based on Type and Drainage Condition (Outlet vs No-Outlet / Sink)

2.2 RESACA SUBWATERSHEDS

2.2.1 Town Resaca Subwatershed

The Town Resaca Subwatershed is unique among the subwatersheds identified and studied in this report. It is a resaca basin as its drainage pathway is an abandoned distributary of the Rio Grande; however, the basin is heavily urbanized (93% developed – see Figure 2-4). The Town Resaca subwatershed's 5.58 sq miles represents about 1.3% of the total LLM / BSC area; however, its population of about 29,000 people represents almost 12% of the population of the LLM / BSC watershed. It has a resulting population density of 5,145 persons / mi^2. This represents the highest population density of any of the subwatersheds in the LLM / BSC and almost 10 times the average basinwide population density of 550 persons / mi^2. Information such as this is available for each of the subwatersheds and subwatershed sections in the LLM / BSC watershed in Table 2-1.

The system serves as the primary stormwater conveyance mechanism for most of downtown Brownsville; as such, its basin boundary is defined by a large, intricate, and complex urban storm sewer network. The natural levees that normally accompany the longitudinal (upstream / downstream) extent of resacas (discussed previously in Section 1.5.2) have largely been developed over or are under-passed by the storm sewer network. As a result, the width (lateral extent discussion in Section 1.5.1) of this Resaca system's subwatershed is much larger than the other Resaca basins in the study area.

There is perceptible baseflow in Town Resaca due to pass-through water being pumped into and through the system by the Brownsville Public Utilities Board (citation required….). This water is pumped for the purpose of maintaining water levels and for providing a minimum amount of water volume in each of the Resaca pools or segments for landscape irrigation, ecological and aesthetic purposes. Water levels in each of the sections of this Resaca system are often maintained at low levels during the rainy season and lowered in anticipation of rainfall events and / or approaching hurricanes.

The majority of the banks of this Resaca system are either privately-owned property (backyards of single family homes) or larger tracts of privately-owned land for businesses and schools. Of particular note, this Resaca flows through the Gladys Porter Zoo – a point of unique interest with respect to bacteria and nutrient loading both from zoo operations and the natural congregation of birds in this area. Of additional importance, about a 0.5 mile stretch of the Resaca was covered by U.S. Highways 77/83 in the 1960s. The entire flow of the Town Resaca system is routed underneath Hwy 77/83 through an underground box culvert. A system of seven weirs located throughout the resaca's length regulates water surface elevations from upstream to downstream. These weirs are not remotely observed nor are they connected to an automated control system such as a SCADA system. The outfall of the system connects to the North Main Drain and follows the NMD drainage route to the Brownsville Ship Channel. In flood situations, Town Resaca stormwater may be pumped to the Rio Grande River via the Impala Pump Stations (see Section 2.3.1).

2.2.1.1 Town Resaca - Population / Land Use Discussion

As can be seen in Figure 2-4, the vast majority of this subwatershed is developed (low to high intensity), with a concentration of high intensity development located in the city downtown core. The southwestern half of the subwatershed is dominated by a large number of approximately 2-acre city blocks (approximately 100 yards on a side). These city blocks are elevated above the street network, a network designed to convey stormwater away from homes and buildings toward the underlying storm sewer network. This downtown city block section is prone to street flooding as a result of the flat terrain, aging storm sewers, and the underlying topography that can be seen via LiDAR to be governed by ancient ox-bows of the Town Resaca system. Recent flood modeling by the National Water Center Summer Institute (2018) shows that flood water collects in streets and preferentially so in streets that are located in the older oxbow systems. (Citation required… cite National Water Center on Brownsville Flooding issues (2 projects with manuscripts in review) work from 2018)

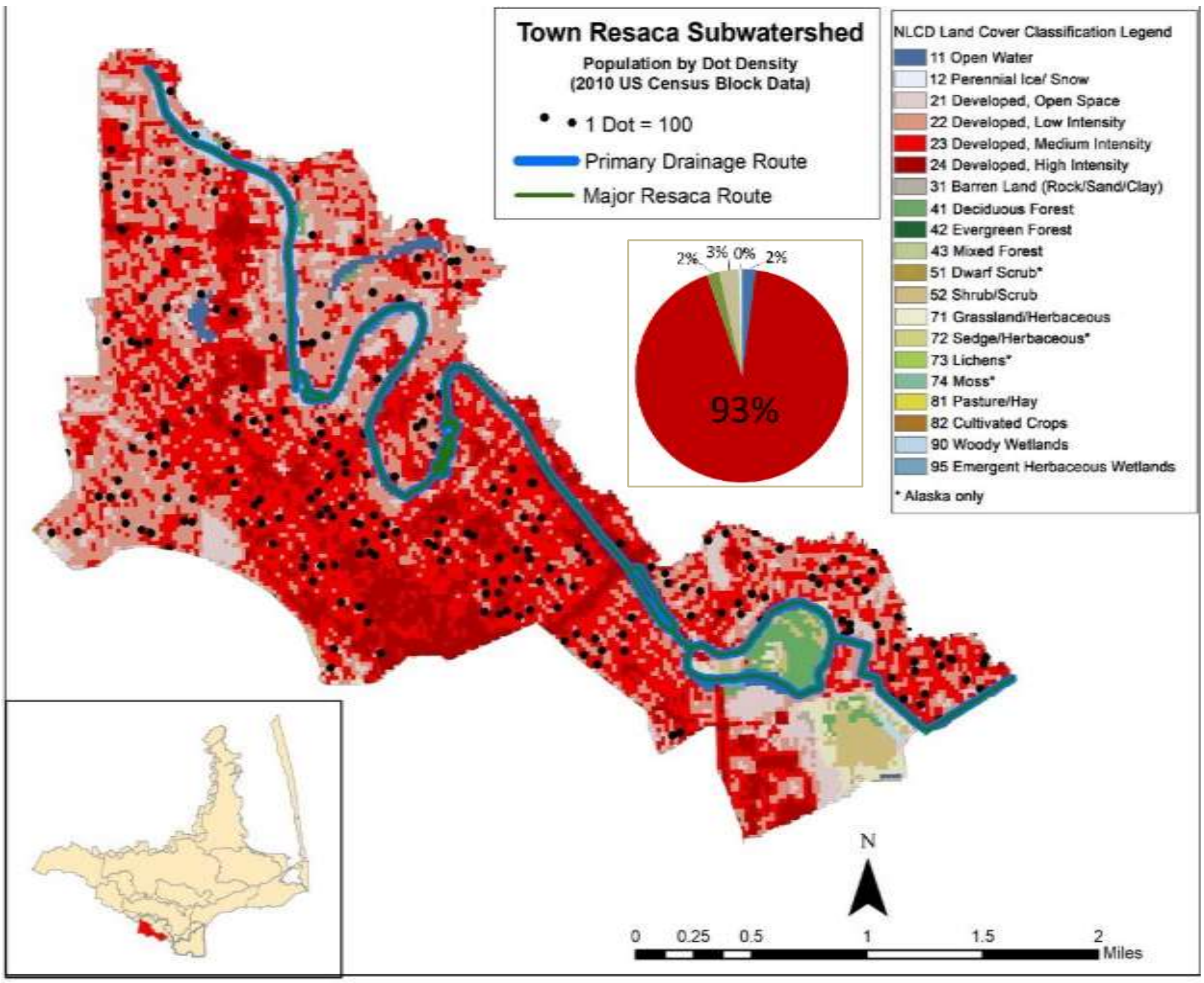


Figure 2-4. Town Resaca Subwatershed (Land Cover, Population Density, Waterways)

2.2.2 Resaca de la Guerra / Palma Subwatershed

The Resaca de la Guerra (RDLG) subwatershed, also commonly referred to as Resaca de la Palma, is characterized by a classic abandoned distributary system of the Rio Grande River that is used for irrigation storage and conveyance, municipal drinking water storage and conveyance, stormwater management and flood protection, as well as playing a vital role in ecosystem support, ecotourism and recreation. The RDLG itself runs through the subwatershed for approximately 31 river miles; however, like all Resaca systems, this reach is intersected and subdivided by a network of roads, railroads, irrigation canals, drainage ditches and hydraulic control structures like weirs, overflow boxes, etc. As a result, the Resaca is segmented into a system of individual river reaches that resemble linear (narrow) lakes, ponds, or pools. The amount of standing and/or flowing water in these individual pools varies depending on recent rainfall, pumped Rio Grande River water, and hydraulic control structures located throughout the reach of the resaca.

Detailing the status and condition of each individual pond in the RDLG is beyond the scope of this report; however, the RDLG itself was divided into two separate sections for the purpose of this study: upstream and downstream. This was done in order to reflect a noted and significant dry portion (disconnection) near the resaca's crossing of Alton Gloor Blvd as well as significant differences in landuse patterns and functions that the Resaca plays upstream and downstream of this location. (Note: The RDLG itself has a few additional pools or segments further downstream of the downstream RDLG subwatershed section. These last few segments, totaling an additional 9.6 river reach miles, are not part of the RDLG subwatersheds due to the fact that they typically serve only irrigation water storage and conveyance. This segment passes through the downstream portion of the NMD subwatershed and the Southmost subwatershed in Figure 2-3 – sometimes becoming part of the primary drainage route of those watershed for a few miles.

Population, population density, and landuse data for the RDLG subwatershed as a whole (combined u/s and d/s sections) can be seen in Figure 2-5. The dividing point between the u/s and d/s sections can be clearly seen in the figure, as well as the differences in watershed width, population density, and landuse patterns. A brief description of each subsection of the RDLG subwatershed follows.

RDLG - Upstream Section

This portion of the RDLG reach totals approximately 12.1 miles in length and its corresponding watershed is comprised of 11.9 mi^2. The subwatershed is characterized primarily by agricultural land use with 50% of its land area being dedicated to agriculture. Low to medium intensity development and shrub/scrub land each occupy 20% of the subwatershed area. There are small areas of deciduous forest located in this area (4% of area) – primarily as part of the Resaca de la Palma State Park area, which is being restored under reforestation plans. The lack of open water (less than 1%) indicates that most of the segments of the RDLG passing through this area are not augmented with irrigation or pass-through water (with the notable exception of the state park segments). It is sparsely populated, with most of the population clustered in small towns located along U.S. Hwy 281. The southern to southwestern basin boundary of this section is determined by the Rio Grande Federal Flood Control Project Levee system.

Due to the apparent lack of the regular conveyance of rainwater by the RDLG in this section based on aerial photo review, LiDAR topographic data review, and land use classification, as well as the intricate network of irrigation canals and associated hydraulic structure and pumps, this subsection should largely be considered a hydrologic sink with respect to stormwater / flood waters. With the exception of severe storm events, regular surface runoff is likely contained in the Resaca pools, infiltrates, and / or is stored by surface depressions as standing water until it is lost to infiltration and evaporation. This conclusion should be revisited and possibly revised if the watershed protection planning process uncovers more information with respect to hydraulic control structures and / or standard water management procedures being following by irrigation and drainage districts responsible for this area.

RDLG - Downstream section

This portion of the RDLG reach totals 18.7 river miles and its corresponding watershed area is comprised of only 4.1 mi^2. This significantly higher river length to watershed area ratio as compared to the upstream section is one of the primary reasons for subdividing this basin. The natural levees (discussed earlier) of this portion of the Resaca are readily apparent in the LiDAR dataset and as a result, limit the area of land contributing surface runoff to this system to a relatively narrow section of land.

This section of the subbain is characterized by low to medium-intensity urban development (approximately 75% of land area). The second largest land use is open water – which results from nearly all of the 18.7 miles of Resaca reach in this section being constantly inundated by water level maintenance water and landscape irrigation water being pumped by the BPUB. There are also numerous ox-bows of the RDLG system in this section, with their water levels regulated by overflow boxes and other hydraulic control structures. This segment of the Resaca system is utilized by BPUB to convey municipal drinking water between Brownsville's two water treatment plants. The land use pattern is similar to Town Resaca – although at lower levels of development intensity and with a bit more riparian (Resaca bank) forest and larger privately-owned homes and yards. Some residential neighborhoods and urbanized areas located directly along the Resaca have stormwater systems that convey stormwater runoff directly to the adjoining resaca pool or segment.

Also similar to Town Resaca, a system of water level control hydraulic structures (weirs, overflow boxes, standpipes, etc.) are located throughout the 18.7 mile reach and permit the control of water levels as land surface elevations decrease found from upstream to downstream in the system. As stated previously, information on the location and type of structures in this and a select portion of other Resaca systems can be found at https://amnovak.github.io/resaca-explorer/.

The downstream section of the RDLG subwatershed terminates at its first confluence with the NMD near where RDLG is crossed by Morningside Road in Brownsville. This confluence is regulated by a combination overflow box connected to the NMD during periods of low flow. During high flow periods, a system of pumps are installed to move excess flood water to the Rio Grande River when necessary. (Citation required….)

The remaining pools or segments of the RDLG system run separate and closely parallel to the NMD for a river reach distance of about 5.2 miles until its second confluence with the NMD flowpath for a distance of 0.5 miles when it heads to the east-southeast toward its final segment near the banks of the Rio Grande River (See Figure 2-1).

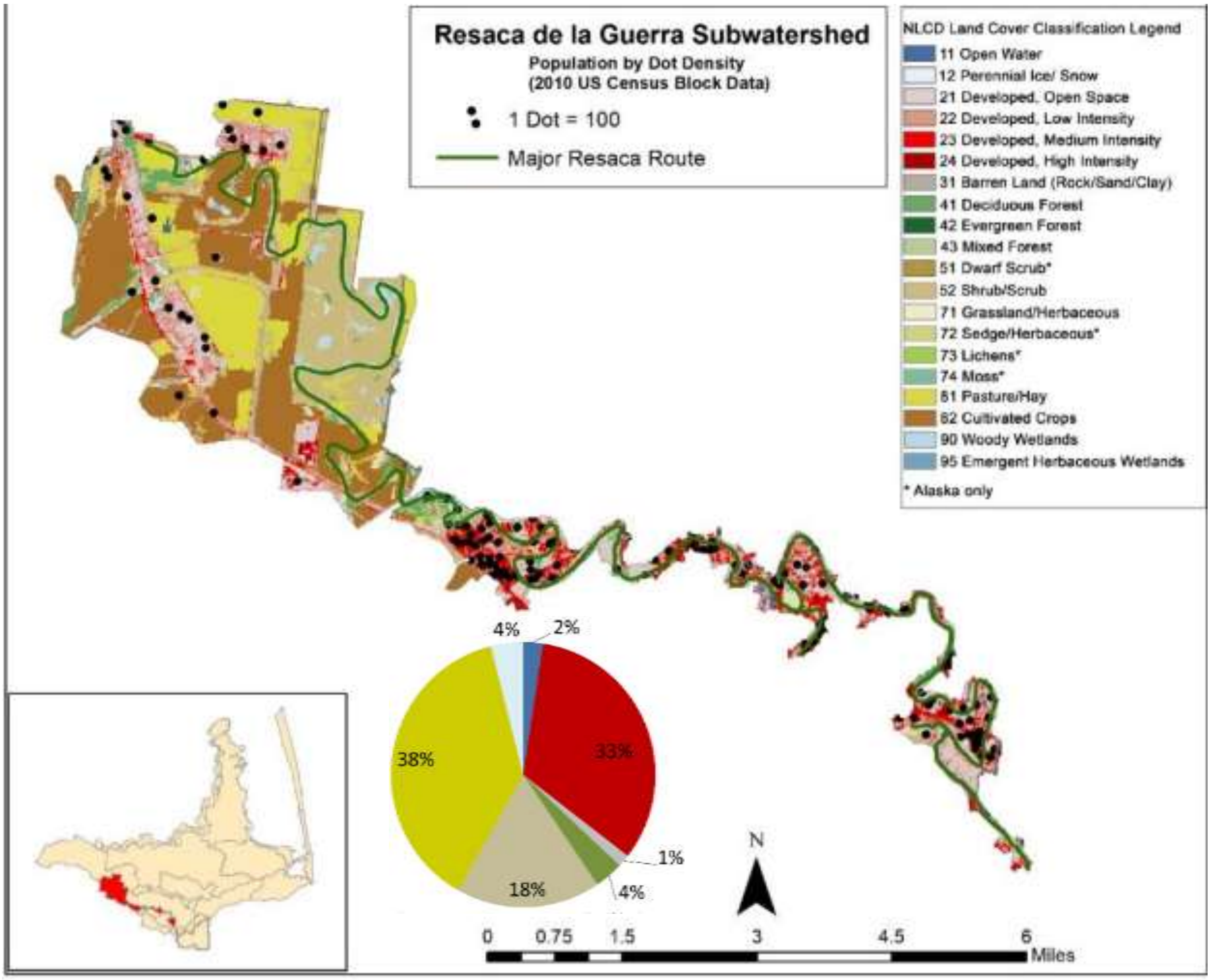


Figure 2-5. Resaca de la Guerra Subwatershed (Land Cover, Population Density, Waterways for both Upstream and Downstream Sections)

2.2.3 Resaca del Rancho Viejo Subwatershed

The Resaca del Rancho Viejo (RRV), also commonly referred to as Resaca Rancho Viejo or Rancho Viejo Resaca, is also a classic Resaca system as defined in previous sections (see Section 1.5). The RRV also serves many functions similar to other resacas such as irrigation and municipal water storage and conveyance, stormwater management, flood protection, etc.

The RRV subwatershed was divided into three sections: upstream, midstream, and downstream. This was done for the same reasons RDLG was subdivided – distinct differences in land use patterns, notable breaks or discontinuity in consecutive pools or segments with maintained water levels, and functions played by the Resaca in that subwatershed section. Taken as a whole, the RRV runs for 51.4 miles (excluding 7.5 miles of additional Resaca segments that are part of other subwatersheds).

Specific data on population, population density, and landuse percentages, watershed area, and river reach length can be found for the RRV subwatershed as a combined unit in Figure 2-6 and Table 2-1.

The dividing points between the sections are demarcated on the figure by the addition of intrabasin section boundaries. A brief description of each subsection of the RRV subwatershed follows.

RRV - Upstream Section

This portion of the RRV reach totals approximately 14.5 miles in length and its corresponding watershed is comprised of 36.4 mi^2 –just over 70% of the area of the RRV subwatershed as a whole. About 5.5 miles of these 14.5 miles of linear segments or pools have their water levels maintained via pumped river water. The remainder of the RRV segments in this section are either wetland or shrub/scrub and only inundated during wet season periods and/or heavy rainfall events. The subwatershed is characterized primarily by agricultural uses with agricultural land cover representing 60% of this section's watershed area. Low to medium intensity development accounts for 19% of the section area, while shrub/scrub makes up approximately 9% of the section area. Similar to the upstream section of the RDLG subwatershed, the 12,600 people in this section are clustered in small towns located along U.S. Hwy 281. This results in a generally low population density of about 348 people / mi^2. The southern to southwestern basin boundary of this section is also delineated by the Rio Grande Federal Flood Control Project Levee system or in some cases, U.S. Hwy 281 proper. Notable features in this section are Reservoir No. 1 and No. 2 in the far western portion of this section and large tracts of land dedicated to and controlled by USFW service as part of the Lower Rio Grande National Wildlife Refuge

For reasons similar to the upper section of RDLG, this upper section of the RRV subwatershed should largely be considered a hydrologic sink with respect to stormwater / flood waters and NPS pollution. With the exception of severe storm events, regular surface runoff is likely contained in the Resaca pools, infiltrates, and / or is stored by surface depressions as standing water until it is lost to infiltration and evaporation. This conclusion should be revisited and possibly revised if the watershed protection planning process uncovers more information with respect to hydraulic control structures and / or standard water management procedures being following by irrigation and drainage districts responsible for this area.

RRV - Midstream Section

This portion of the RRV reach totals approximately 16.2 miles in length and its corresponding watershed is comprised of 9.3 mi^2. About 8.3 river miles of these 16.2 miles of linear segments or pools are utilized by the Valley Municipal Utility District (No.2) for the purpose of storing and conveying municipal and irrigation water. This wet segment of the midstream section corresponds mostly with the City of Rancho Viejo and portions of the City of Olmito. The remainder of the RRV segments in this section are either wetland or shrub/scrub and are only inundated during wet season periods and/or heavy rainfall events. The subwatershed is characterized primarily by agricultural land use with 51% of its land area being dedicated to agriculture. Low to medium intensity development accounts for 18% of the section area, while shrub/scrub makes up approximately 15% of the section area. Similar to the upstream section of the RRV subwatershed, this section is sparsely populated, with most of the population clustered in the fairly open-space dominated City of Rancho Viejo and the small town of Olmito – both along U.S. Hwy 77/83. The total population of this section is approximately 2,700 with a resulting population density of 290 people per mi^2.

It is difficult to determine whether or not this section of the RRV subwatershed is hydraulically / hydrologically connected to any other downstream subwatershed. An analysis of aerial photography and discussions with relevant personnel show that there is a large, relatively dry and overgrown 5.2 mile length of the RRV that does not appear to convey flood water in the downstream direction on a regular basis. As such, and for similar reasons as the upstream RRV section, this middle section may be considered a hydrologic sink; however, there are a few possible locations (as determined by aerial photography and hydrography datasets) where connections to the San Martin Subwatershed might exist – primarily through a connection to Main Ditch No. 3.

RRV - Downstream section

This portion of the RRV reach totals approximately 20.7 miles in length and its corresponding watershed is comprised of only 5.5 mi^2. As was the case for the lower section of the RDLG subwatershed, the natural levees (discussed earlier) of this portion of the Resaca are readily apparent in the LiDAR dataset and as a result, limit the area of land contributing surface runoff to this system to a relatively narrow section of land. This can again be clearly seen in Figure 1-8 (LiDAR image). Additionally, nearly 90% of the resaca reach is utilized by the BPUB and the BID for the purpose of landscape irrigation and agricultural water storage and conveyance. The remainder of the RRV segments are either wetland or shrub/scrub and only inundated during wet season periods and/or heavy rainfall events.

The subwatershed has 39% of its land area taken up by open-space and low intensity urban development (mostly single family homes with large yards – with the notable exception of the Cameron Park colonia). 17% of its land is agriculture and 14% is shrub/scrub. About 10% of its land area is deciduous forest – mostly due to dedicated reforestation efforts in fallow agricultural land by Texas Parks and Wildlife. This section of the RRV subwatershed is significantly more densely populated than its other sections, with approximately 1,360 people per mi^2. Open water represents about 10% of the land area, a relatively large area due to the same reasons as the lower section of the RDLG subwatershed – segments being constantly inundated by pass-through and landscape irrigation and agricultural water. There are also numerous ox-bows of the RRV system in this section, with many of them being used for water storage and with their water levels regulated by overflow boxes and other hydraulic control structures. Some neighborhoods located both along or near the Resaca have stormwater systems that are able to drain to the nearest resaca pool or segment and utilize the resaca for flood management.

Also similar to both Town and RDLG, a system of water level control hydraulic structures (weirs, overflow boxes, standpipes, etc.) are located throughout this section and permit the control of water levels as land surface elevations decrease found from upstream to downstream in the system. As stated previously, information on the location and type of structures in this and a select portion of other Resaca systems can be found at: https://amnovak.github.io/resaca-explorer/ (Note: This website is not optimized for Microsoft Explorer and is ideally viewed in either Google Chrome or Safari.)

The downstream section of the RRV subwatershed terminates as it nears Cameron County Drainage Ditch No.1. It is uncertain whether or not there is a hydraulic structure connecting RRV and CCDD No.1 near Texas Hwy 48 (South Padre Island Blvd) and FM 802. Overflow water in this Resaca system is designed to be accommodated by the Rancho Viejo Floodway which offshoots from RRV near FM 511 about 0.5 miles NW of the FM 511 and Hwy 48 intersection. This floodway is broad and long (500 ft by 2.3 miles) and is likely very rarely at capacity. However, the floodway does connect to CCDD No. 1 via an overflow route about 2.7 miles further downstream. The National Hydrography Dataset shows other possible overflow routes to San Martin (Main Ditch No.2); however, all routes eventually guide this water to the Brownsville Ship Channel via San Martin Lake.

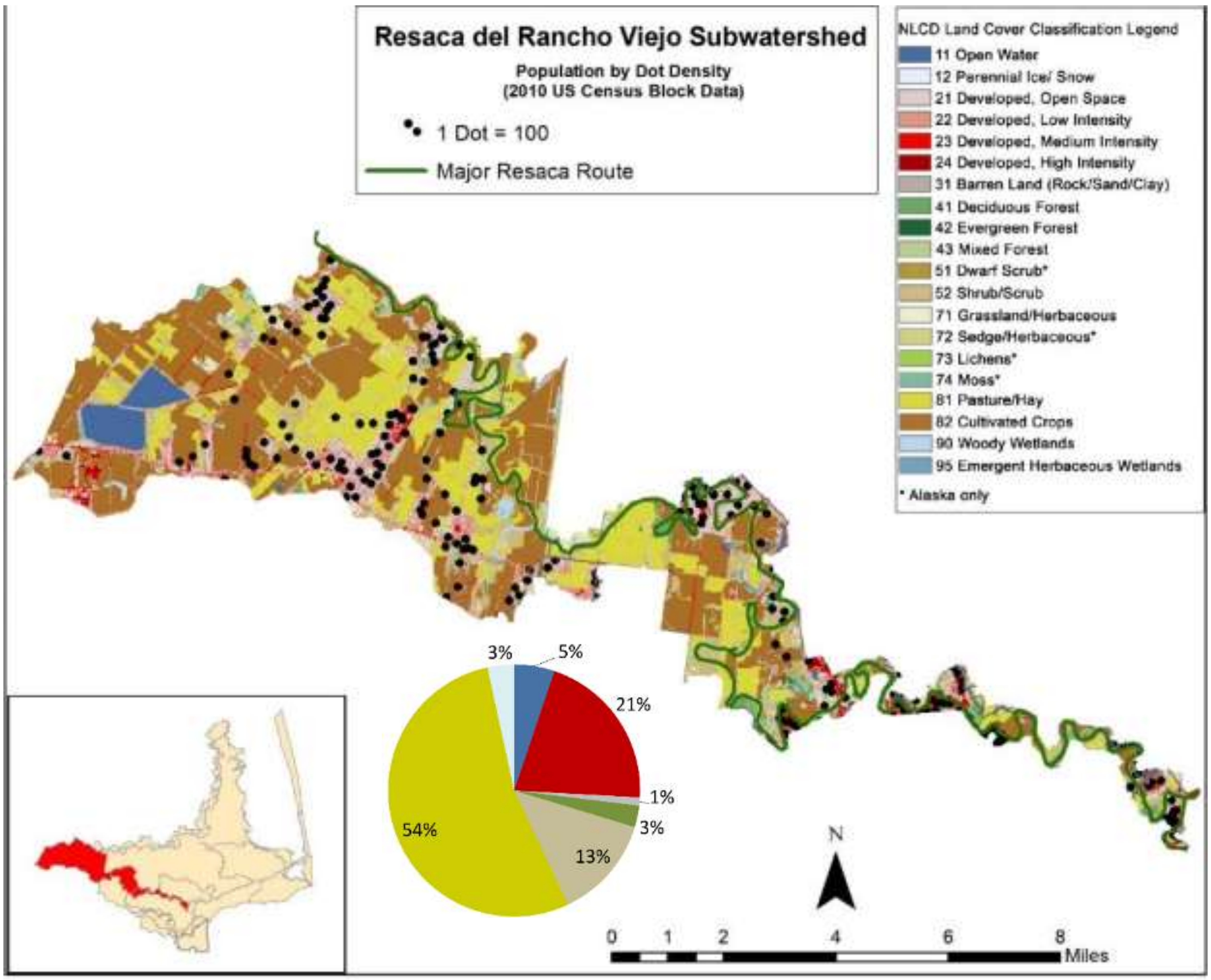


Figure 2-6. Resaca del Rancho Viejo Subwatershed (Land Cover, Population Density, Waterways for Upstream, Midstream, and Downstream Sections)

2.2.4 Resaca de los Cuates Subwatershed

The Resaca de los Cuates (RDLC) subwatershed the largest distributary system of the Rio Grande in the study area – approximately 70.8 river miles in length. It forms the northern boundary of most of the LLM / BSC watershed and its system of natural levees form the topographic boundary between the LLM / BSC and Arroyo Colorado watersheds to its north. The RDLC is hydrographically and hydraulically similar to both the RRV and RDLG; however, it is principally used for agricultural and municipal water storage and conveyance. This system can be seen in LiDAR topography and soil datasets to be a major distributary of the Rio Grande, and in fact, a significant distributary fan of older, smaller resaca systems can be seen emanating from the RDLC around the Bayview, Texas area (see Figure 1-8). The RDLC is unique among the other resaca systems in the LLM / BSC in that its historic flowpath connects directly to the Lower Laguna Madre near the mouth of the Arroyo Colorado. (See Figure 2-1).

The RDLC subwatershed was divided into two sections: upstream and downstream. In this case, the division occurs at a point just downstream of Bayview, Texas, where the RDLC system is no longer utilized for water conveyance. This results in distinctly different physical, visual, hydrologic, and ecological conditions between the two sections. The upstream section was once historically connected to the RRV system just west of Lago, Texas near US HWY 77/83 between the City of Rancho Viejo and San Benito, Texas. The system hydrologically now begins at the RDLC Reservoir (Laguna Madre Water District – Reservoir #4). The system flows under US HWY 77/83 and continues through the cities of Los Fresnos and Bayview. The upstream section is approximately 38 river miles in length and terminates at a final hydraulic weir just downstream of Bayview. The lower section of the RDLC begins at this point and runs northward through the Laguna Atascosa National Wildlife Refuge, between Cayo Atascosa and the Lower Laguna Madre proper. During the downstream section's 32 mile run, the system becomes more and more a remnant, dry,coastal feature – characterized by sharply eroded natural levees to the point the eastern (seaward) natural levee is often gone. This erosion is due to a combination of factors including coastal / tidal erosion, wind erosion, and hypersalinity of soils preventing dense vegetation. The thalweg of the old resaca bed, however, is still prominent with banks over 5-8 ft. The system becomes less and less prominent topographically as it nears its terminus near confluence of the mouth of the Arroyo Colorado and the LLM.

Population, population density, and landuse data for the RDLC subwatershed as a whole (combined u/s and d/s sections) can be seen in Figure 2-7 and Table 2-1. A brief description of each subsection of the RDLC subwatershed follows.

<u>RDLC - Upstream Section</u>

This portion of the RDLG reach totals approximately 37.9 miles in length and its corresponding watershed is comprised of 16.5 mi^2. The subwatershed is characterized primarily by agricultural land use with 47% of its land area being agriculture. Open water, Low to medium intensity development, and shrub/scrub each comprise 14% of the land area. The larger open water percentage is due to the fact that the upstream section of the RDLC system is wider than many of the other resaca systems in the LLM / BSC, with many of its segments nearly 300 feet wide. There are long, but narrow, stretches of deciduous forest on the dry side of the natural levees (riparian brushland). There are sometimes emergent wetlands on the wet side of the natural levees and along the banks of many of the segments in this system. Population in this upstream section is mostly clustered in the cities of Los Fresnos and Bayview.

This upstream section of the RDLC is heavily used for agricultural and municipal water conveyance. As a result, it is uncommon to see even moderate fluctuations in water surface levels and the residence time of the water in this system is likely significantly lower than other resaca systems in the area. Combining this with the fact that there are few stormwater systems dependent on this system for flood management and the fact that agricultural return water does not return to the resaca system, but instead is collected by a system of tile drains and drainage ditches, it is expected that the water quality in this system most strongly resembles its source water – the Rio Grande River. There are also a significant number of ox-bows in this stretch of resaca, and many of them are used for additional water storage and distribution.

RDLC - Downstream section

This portion of the RDLC reach totals 32.9 river miles and its corresponding watershed area is comprised of 13.5 mi^2. The natural levees of this portion of the Resaca are less apparent in the LiDAR dataset and as a result, the basin boundary is more often defined by the thalweg (lowest elevation portion) of the resaca stream bed - which in this section, is often dry.

The downstream section of the RDLC is characterized primarily by emergent, herbaceous wetland near its terminus along the coast (39% of section area). The more upstream portion is dominated by agriculture (17% of section area) and the middle portion of this section is mostly shrub / scrub (15% of section area).

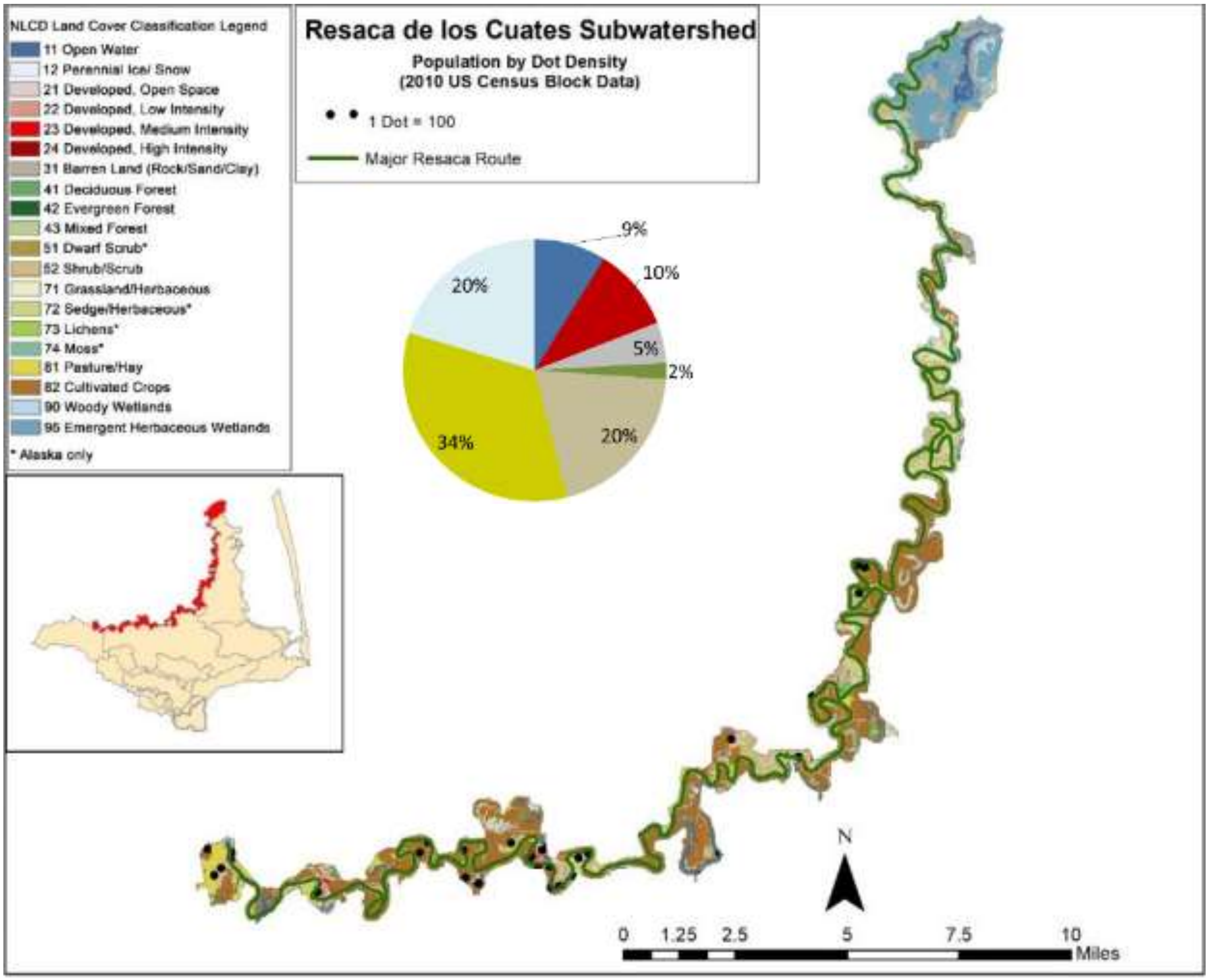


Figure 2-7. Resaca de Los Cuates (Land Cover, Population Density, Waterways for Upstream and Downstream Sections)

2.3 PRIMARY DRAINAGE SUBWATERSHEDS

2.3.1 North Main Drain Subwatershed

The North Main Drain subwatershed (see Figure 2-8), is located between the Town Resaca and Resaca de la Guerra (Palma) watersheds. The North Main Drain itself, in fact, drains the low-lying areas between the natural levees of these two resaca systems (See LiDAR Figure 1-8). The drain runs from west to east across and through some of Brownsville's most densely urbanized areas. The drain is approximately 14.5 miles long from its start just east of the intersection of US HWY 281 and FM 802 to its confluence with the Southmost Drain just before they both outfall into the Brownsville Ship Channel. The subwatershed area is approximately 11.1 square miles.

The NMD principally conveys urban stormwater from runoff and collection drains throughout its own watershed; however, it also serves as the outfall for Town Resaca and Resaca de la Guerra (Palma) – conveying the flows of all three systems to the Brownsville Ship Channel.

The NMD subwatershed's land use breakdown is shown in Table 2-1. The primary landuse is low to high density urban development (78%) along with some commercial / industrial land uses (see Figure 2-8).

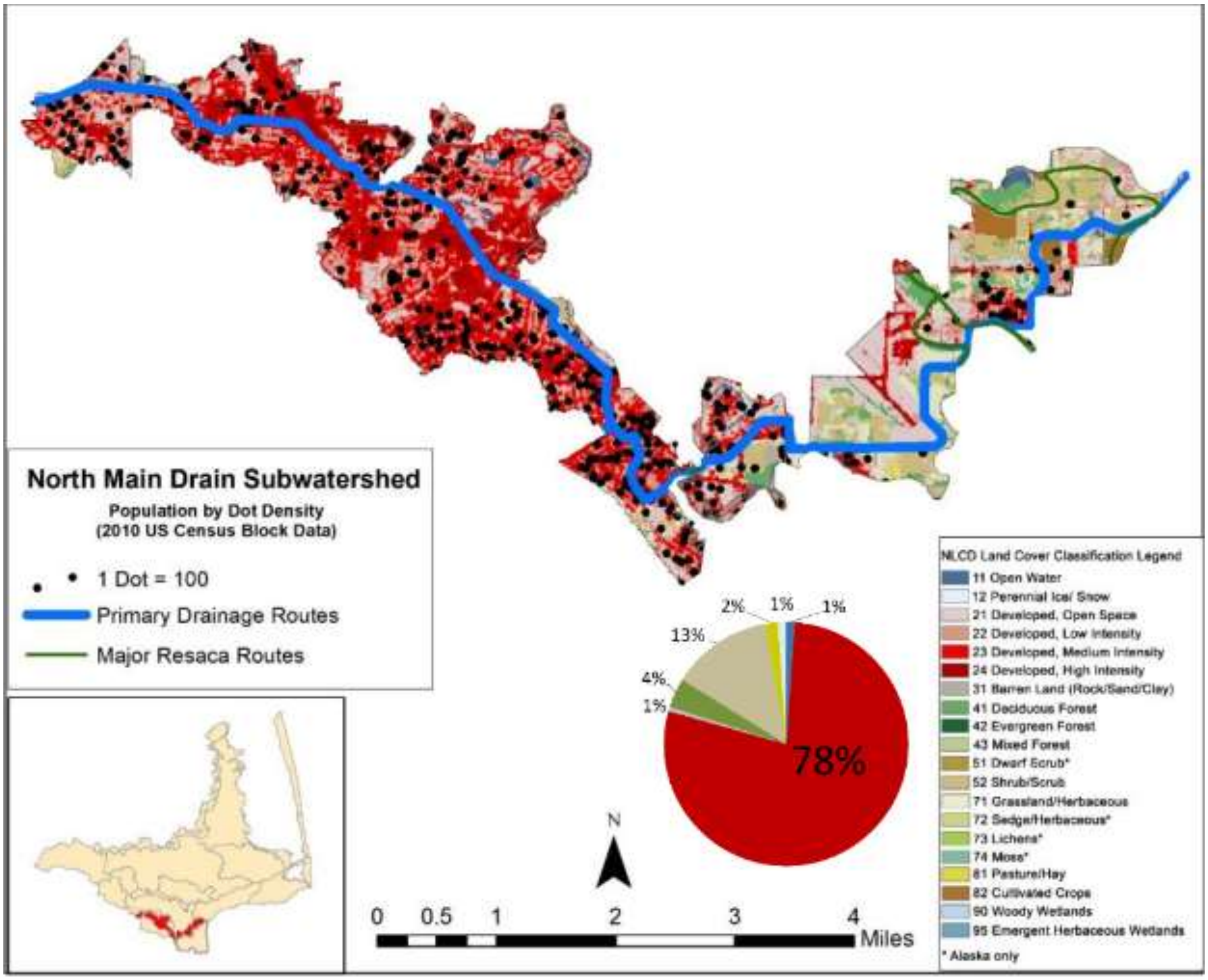


Figure 2-8. North Main Drain Subwatershed (Land Cover, Population Density, and Waterways)

The NMD plays just as critical a role in flood protection for the urbanized sections of Brownsville as Town Resaca. And given the fact it receives the outfall of TR, the NMD is possibly the most critical flood control infrastructure for downtown and densely developed portions of the City of Brownsville. There are a growing number of offline flood detention ponds being constructed along its urbanized sections that aim to alleviate the flooding often experienced around this important ditch. The complex network of overland flowpaths and stormwater systems that flow into the NMD are beyond the scope of this report, but in general, non-point source pollution is conveyed rapidly to the primary drainage path in this system given its rather narrow and elongated subwatershed shape.

The importance that the NMD system plays in flood protection is highlighted by the fact that its subwatershed's population is the largest in the study area at approximately 43,000 people and a resulting population density of nearly 3,900 people per square mile. The upstream 8 miles of the NMD are the most heavily urbanized, with a population density of almost 7,500 people per square mile.

2.3.2 Southmost Drain Subwatershed

The Southmost Drain subwatershed is located in the southernmost bend of the Rio Grande River (see Figure 2-3) and conveges with the drainage path of the NMD and continues to the Brownsville Ship Channel. The subwatershed is approximately 13.1 square miles and its primary drainage ditch is about 7.25 miles long. Its landuse pattern is dominated by agricultural landuse (46%), followed by about 28% "open space to low-intensity" urban development (Figure 2-9). The Southmost subwatershed is also 13%.Shrub/scrub with a small, but growing (5%+) area of forest, particularly along the resaca systems that pass through its area (RDLG) and in the Sabal Palms Sanctuary and other protected areas along the Rio Grande River. The southern and eastern subwatershed boundaries are formed by the Rio Grande River Federal levee. Its northern boundary is mostly determined by the natural levees of the remnant, downstream sections of the RDLG. It is important to point out that the subwatershed's agricultural land is drained by a rapidly aging and poorly maintained tile drainage system consisting of approximately 50+ miles of collecting drains. This subwatershed is also crossed by the most downstream, remnant sections of both the RDLG and the RRV.

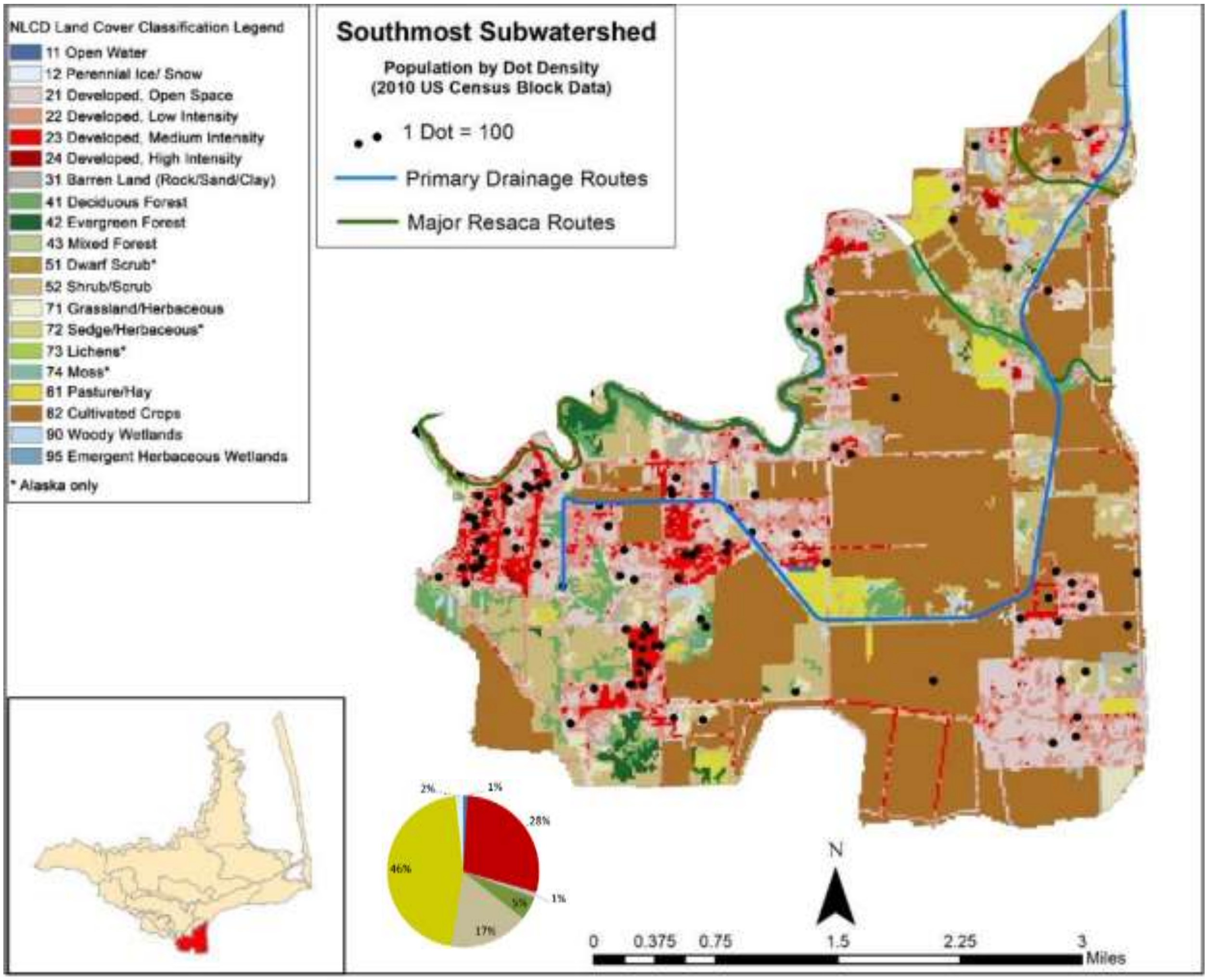


Figure 2-9. Southmost Drain Subwatershed (Land Cover, Population Density, and Waterways)

2.3.3 Cameron County Drainage District No. 1 (CCDD#1) Subwatershed

The Cameron County Drainage Ditch No. 1 subwatershed (Figure 2-10) is the large, 25.8 square mile low-lying area between the RDLP and the RRV. The lower elevation of this subwatershed is clearly visible in the LiDAR topography shown in Figure 1-8. The drainage ditch, along with its major contributing ditches, runs for approximately 19 miles, with an additional last 2 miles running through the Loma Alta Subwatershed on its way to merging with the San Martin Drain (Main Ditch #2) continuing on through San Martin Lake and into the Brownsville Ship Channel. The subwatershed's primary landuse is low to medium-intensity urban development (approximately 70%), which includes a notable industry / manufacturing district dominated by warehouses, storage facilities, and truck depots. CCDD#1 is a vital drainage system for a large portion of the LLM / BSC area. It runs from west to east across northern Brownsville until the drain sharply redirects to the northeast, running parallel to the Rancho Viejo

Floodway and near-parallel to the westernmost extent of the BSC.

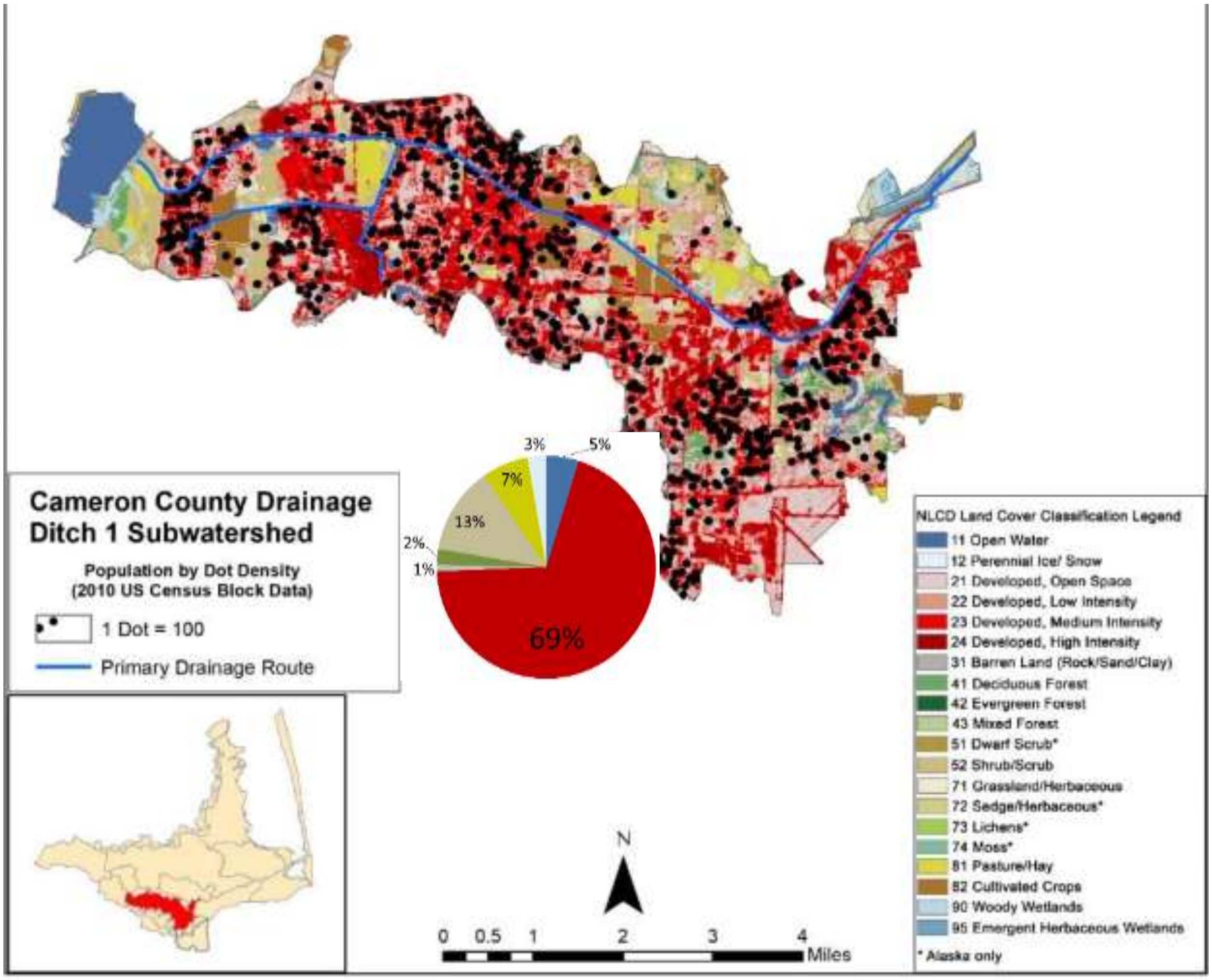


Figure 2-10. Cameron County Drainage District No .1 Subwatershed (Land Cover, Population Density, and Waterways)

2.3.4 San Martin Lake Subwatershed

The San Martin Lake subwatershed is the largest subwatershed in the LLM / BSC study area. It covers approximately 93 square miles with a starkly divided landuse pattern between its western and eastern (more coastal) portion (Figure 2-11). The entire watershed is comprised of approximately 38% wetlands (mostly coastal), 21% agriculture, 16% shrub/scrub, and 13% developed land (open-space to low-intensity). The western portion of this subwatershed is bounded by the RRV (to the south) and the RDLC (to the north). A major brackish groundwater desalination plant (Southmost Regional Water Authority – SRWA) is located off of FM 511 in this subbasin and contributes baseflow to the drain by way of returned reverse osmosis concentrate discharge (citation with more information required). The eastern boundary is dictated by the western edge of the coastal subwatersheds of the LLM and the Bahia Grande / Vadia Ancha subwatershed. The subwatershed includes predominantly agricultural land use in its western and northwestern portion and vast amounts of coastal wetlands and shrub / scrub in its eastern portion toward the Brownsville Ship Channel. Delineation of the boundaries of this subwatershed were particularly challenging due to the intricate network of drainage, spoil bank ditches, irrigation canals, and flat, coastal terrain present throughout much of its area. Additionally, there are several locations where canals and/or ditches intersect the RRV and the RDLC. These connections are likely regulated by hydraulic structures, but a few of them seem to be open connections. It is beyond the scope of this report to detail each of these in detail – and it is thus advised that the Partnership study these more carefully if it is determined necessary for modeling purposes and for specific implementation strategies in the watershed protection plan.

The ditch itself runs for 28.5 miles from starting points in the western portion of the subwatershed until its junction with CCDD#1. The drainage ditch then continues for an additional 5.7 miles through the San Martin Lake systems, finally reaching the BSC.

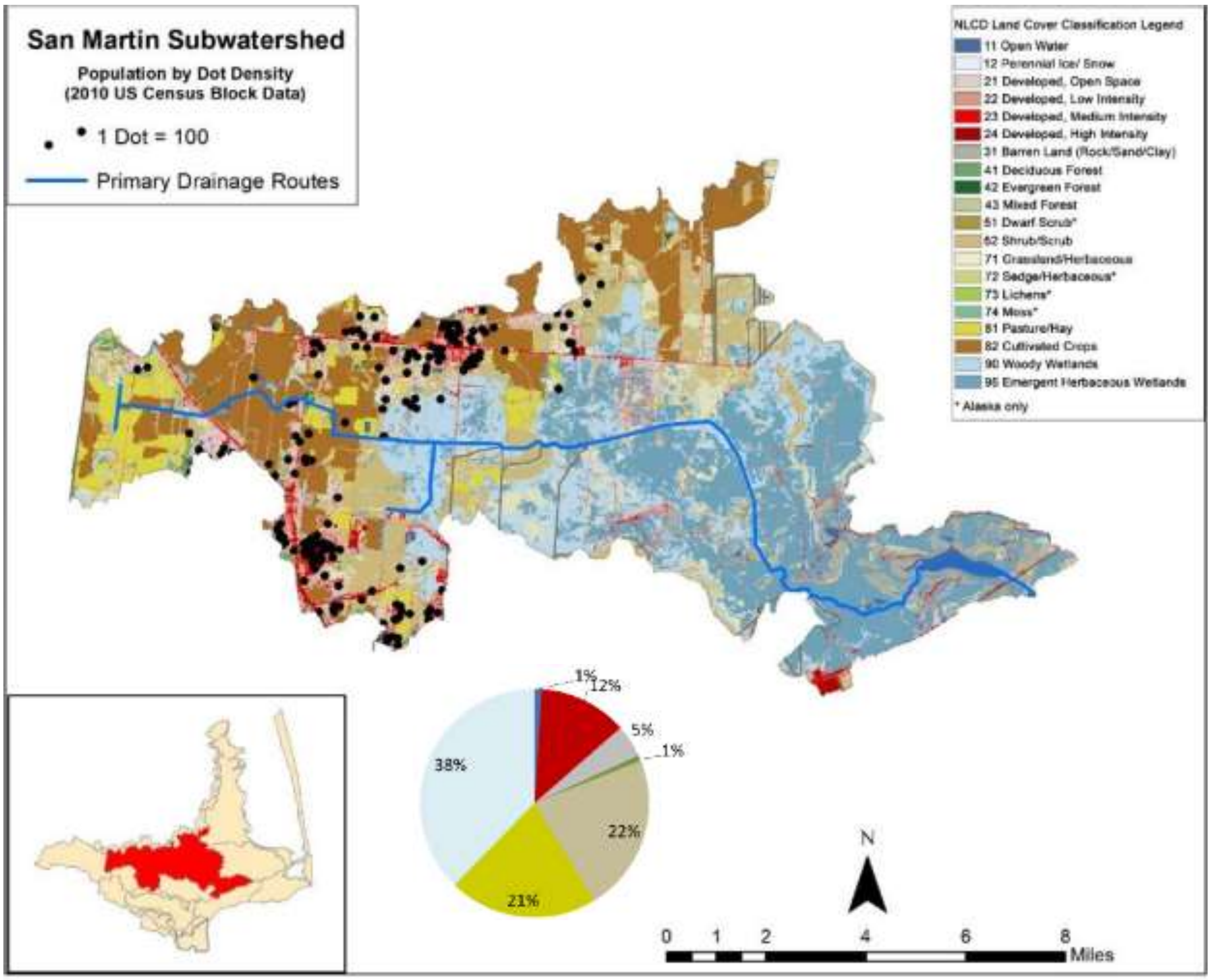


Figure 2-11. San Martin (Lake) Subwatershed (Land Cover, Population Density, and Waterways)

2.3.5 Loma Alta Subwatershed

The Loma Alta subwatershed is a smaller subwatershed of approximately 18 square miles and is subdivided by Farm Road 511. The basin is 40% coastal and emergent wetlands, 18% grasses, and 16% shrub / scrub (Figure 2-12). The primary drainage pattern runs for approximately 8.5 miles before merging with CCDD#1. West of FM 511, the subwatershed has some urban development and agriculture along with shrub/scrub. East of FM 511, Loma Alta is predominantly woody and emergent herbaceous wetlands (coastal) and a mix of shrub / scrub and grasses. Loma Alta Lake is the predominant feature in this subwatershed. Loma (Spanish word meaning hill, prominence, or knoll) is locally used to describe the numerous clay dunes found in the Rio Grande River delta – particularly around to the north and northwest of the current route of the Rio Grande River itself. Like all lomas in the area, they are developed by clay fines being blown by the predominantly southeasterly winds. This wind erosion results in a blowout or depressed area being developed (forming a lake or bay) and a clay dune being developed to the lake area's northwest. The population of about 2,000 people are clustered in developed areas found only to the southwest of FM 511.

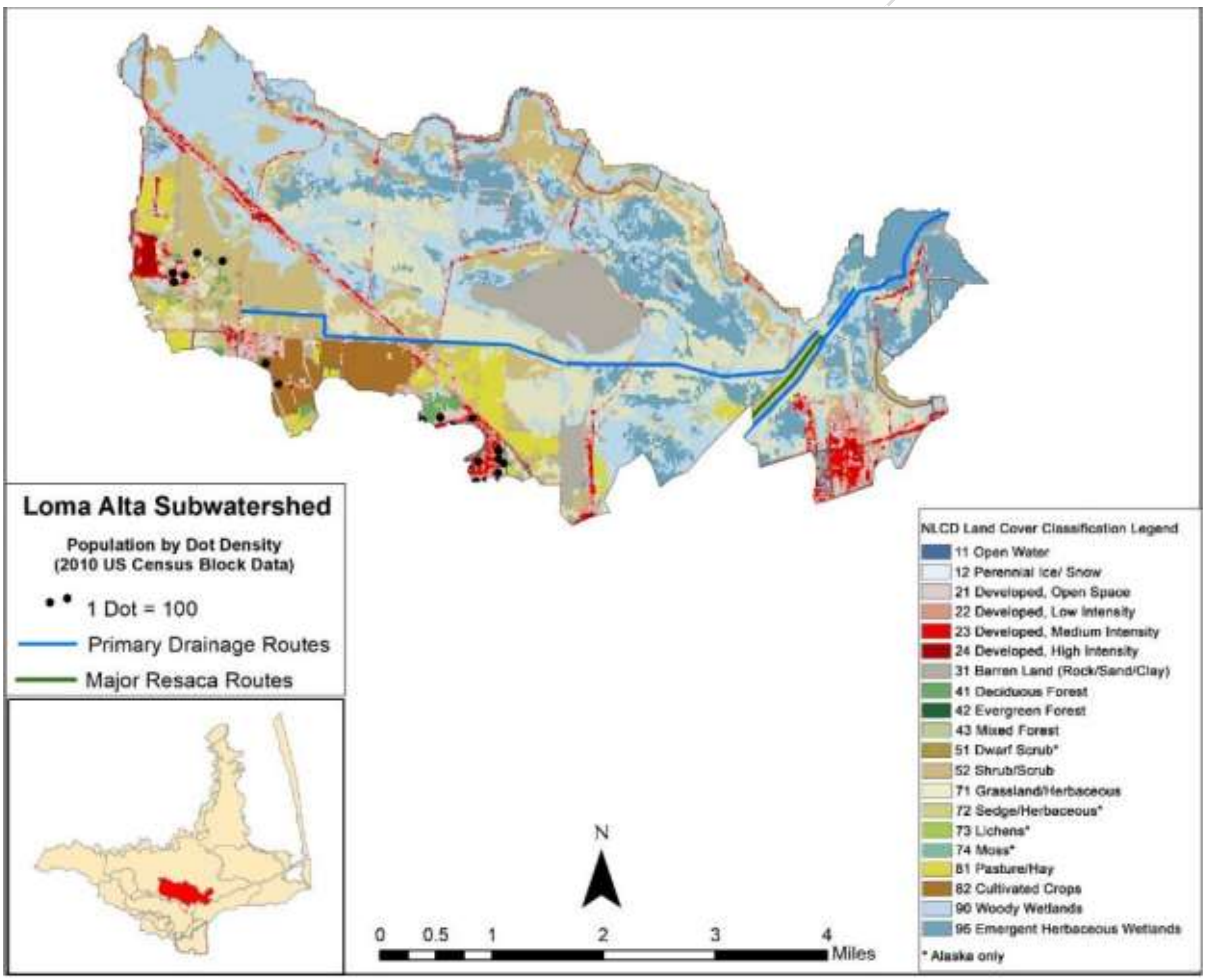


Figure 2-12. Loma Alta Subwatershed (Land Cover, Population Density, and Waterways)

2.4 COASTAL SUBWATERSHEDS

2.4.1 Lower Laguna Madre (LLM) Subwatershed

The 62.0 square mile subwatershed is a major coastal basin in the LLM / BSC. It is bounded on the west by RDLC and the LLM coastline to the east. Its southern boundary is generally defined by Highway 100.

Due to its proximity to the coast and the resulting flat and low-lying terrain, this and the remainder of the coastal basins in this report lack a natural, well-defined drainage feature. The LLM, in particular, has numerous man-made drains and irrigation canals (and/or ditches that may function as both) throughout the basin. Many begin along its western boundary with the RDLC and terminate at the LLM. The basin is approximately 37% wetlands, 17% barren land, and 17% shrub / scrub (Figure 2-13). An archaic, remnant of a distributary feature of the RDLC is present on USGS maps in this subwatershed and is called “Resaca de la Gringa.”

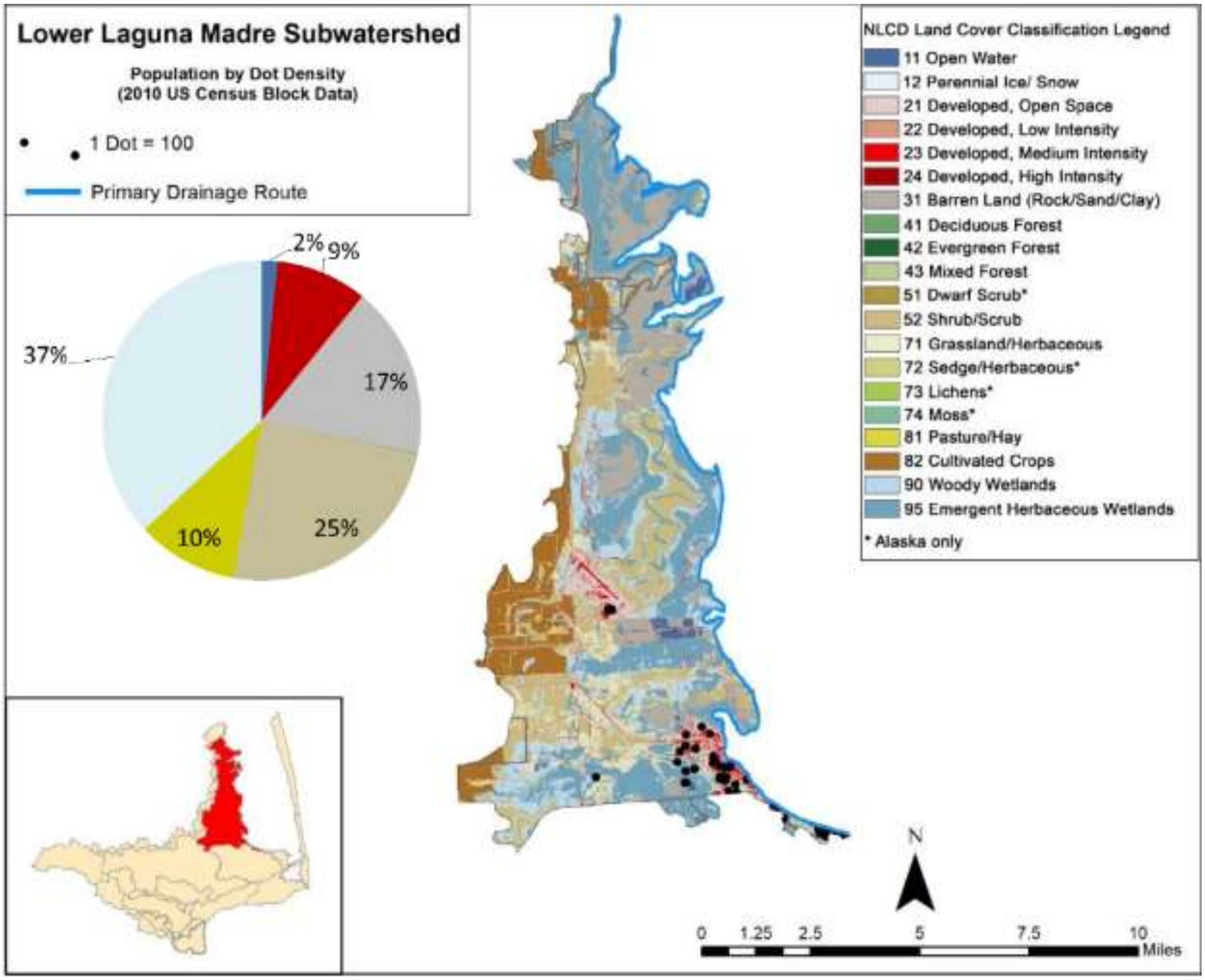


Figure 2-13. Lower Laguna Madre Subwatershed (Land Cover, Population Density, and Waterways)

2.4.2 Port of Brownsville Subwatershed

The subwatershed has a land area of approximately 20.8 square miles. It is the receiving subwatershed for both main outfalls for the non-coastal subwatersheds: the NMD/ Southmost / TR / RDLG outfall (southern outfall) and the San Martin (CCDD#2 and #3) / RRV / CCDD#1 outfall (northern or San Martin Lake). This area is mostly barren and/or developed (industrial) land, spoil material from the BSC, and/or coastal wetlands / marsh (see Figure 2-14). This subwatershed was included primarily for the purpose of spatially delineating the Port, its operations, and potential future port activity that may impact water quality including, but not limited to: Liquified Natural Gas transfer facilities, manufacturing plants, future ship-breaking operations, etc. There is a small, populated area of about 600 persons in the far southwestern portion of the Port subwatershed. The City of Brownsville landfill is also located in this subwatershed.

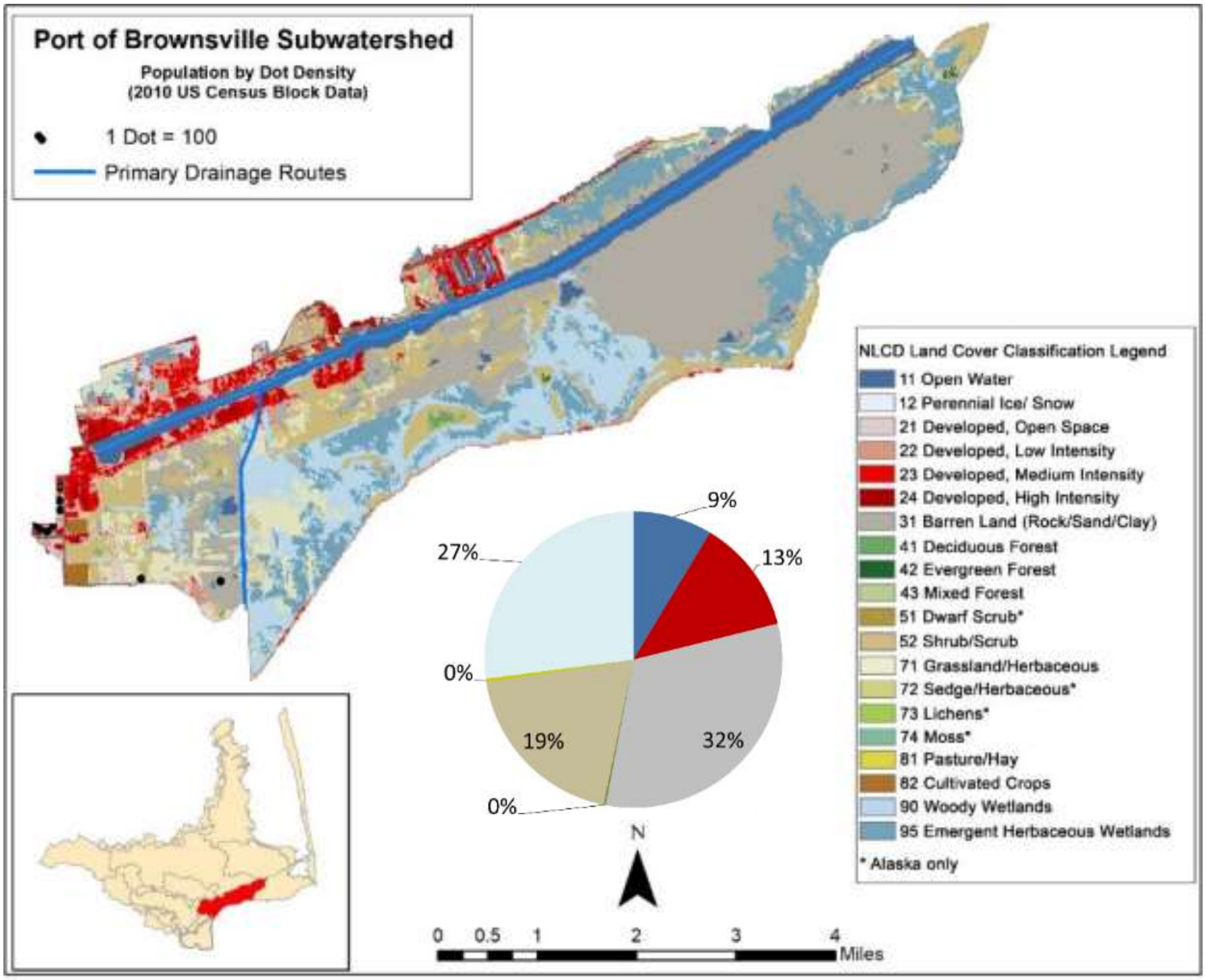


Figure 2-14. Port of Brownsville Subwatershed (Land Cover, Population Density, and Waterways)

2.4.3 Bahia Grande / Vadia Ancha Subwatershed

This 39 mi^2 subwatershed is dominated by a large, interconnected coastal bay system that is hydrologically connected to the Brownsville Ship Channel via pilot channels and low-lying passages between and around the clay dunes (lomas) in this area. The bay system consists of the larger Bahia Grande, the Laguna Larga, and the Little Laguna Madre (Figure 2-15). The Vadia Ancha connects this three-bay complex to the Brownsville Ship Channel on the eastern side of the subwatershed, while the Carl J. Gayman Pilot Channel connects the Bahia Grande to the BSC along its southern boundary. There is no development and / or people in the subwatershed with the exception of a small portion of a neighborhood in Laguna Heights that was included in the basin by LiDAR topographic analysis. This was intentionally left as estimated by the automated process because it is feasible that Hwy 100 may form a subwatershed divide resulting in part of the City of Laguna Heights draining to the Bahia Grande bay complex.

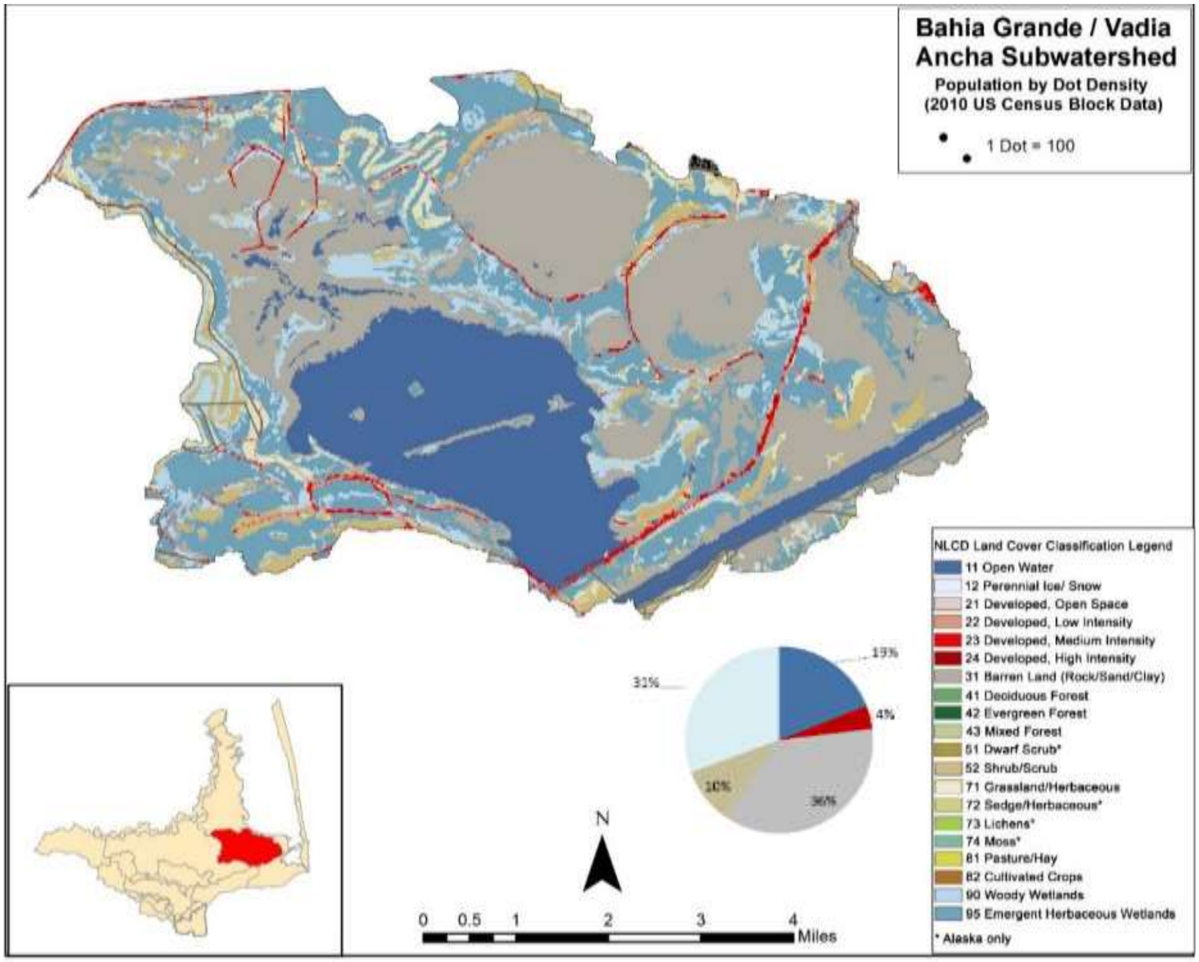


Figure 2-15. Bahia Grande / Vadia Ancha Subwatershed (Land Cover, Population Density, and Waterways)

2.4.4 South Bay Subwatershed

This 26 mi^2 subwatershed is defined by the South Bay system, which was historically part of the Lower Laguna Madre before construction of the BSC and the man-made island portion of the City of Port Isabel. The basin is dominated by coastal wetlands (51%) and barren land (24%), with 19% open water area (Figure 2-16). The South Bay water area itself is not included in the subwatershed area as it is hydrologically connected to and regularly flooded by the Laguna Madre. A very small population of 16 or so people is limited to the Kopernik Shores development along Texas Hwy 4 near Boca Chica Beach. The southern boundary of of this system is defined by the Rio Grande River system itself and/or Hwy 4 proper. The western boundary is defined by an elevated (3-7 ft elevation) stretch of land that was once likely a series of connected lomas. The northern boundary is the BSC and the eastern boundary the Gulf of Mexico at Boca Chica Beach / Brazos Island. The South Bay basin may become a point of interest for non-point and point source pollution in the future given the potential for industrial development associated with SpaceX operations along and near Boca Chica beach.

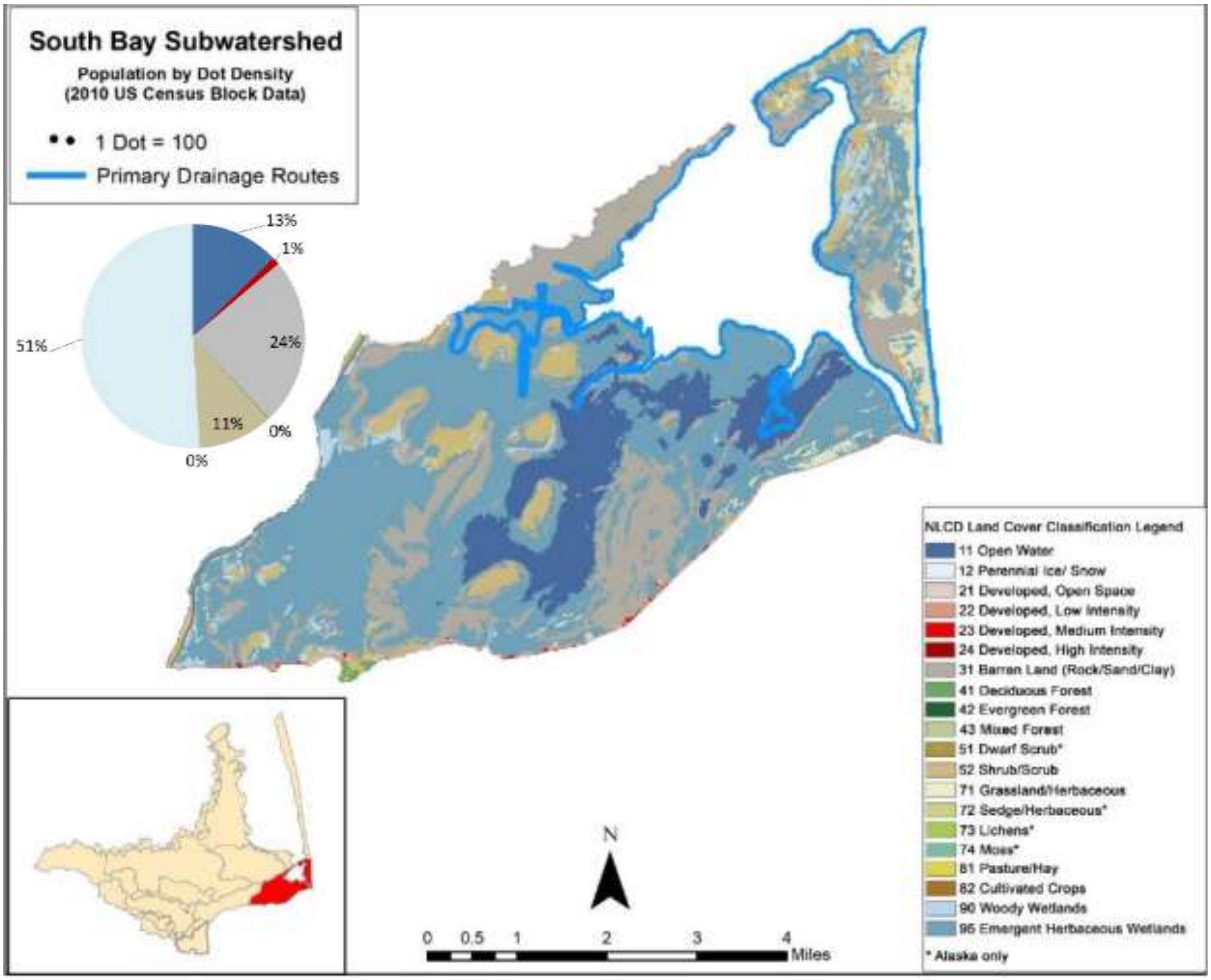


Figure 2-16. South Bay Subwatershed (Land Cover, Population Density, and Waterways)

2.4.5 Port Isabel Subwatershed

The Port Isabel Subwatershed is a small, 4.4 mi^2 urban, coastal area that contains the City of Port Isabel, Port Isabel itself, Long Island, and a small section of Laguna Heights. This area is predominantly (43%) medium to high-intensity urban development with some industrial use in and around the port area (Figure 2-17). The population of approximately 6,300 people is clustered in Port Isabel proper. There is a significant amount of pass-through vehicular traffic associated with tourism to and from South Padre Island.

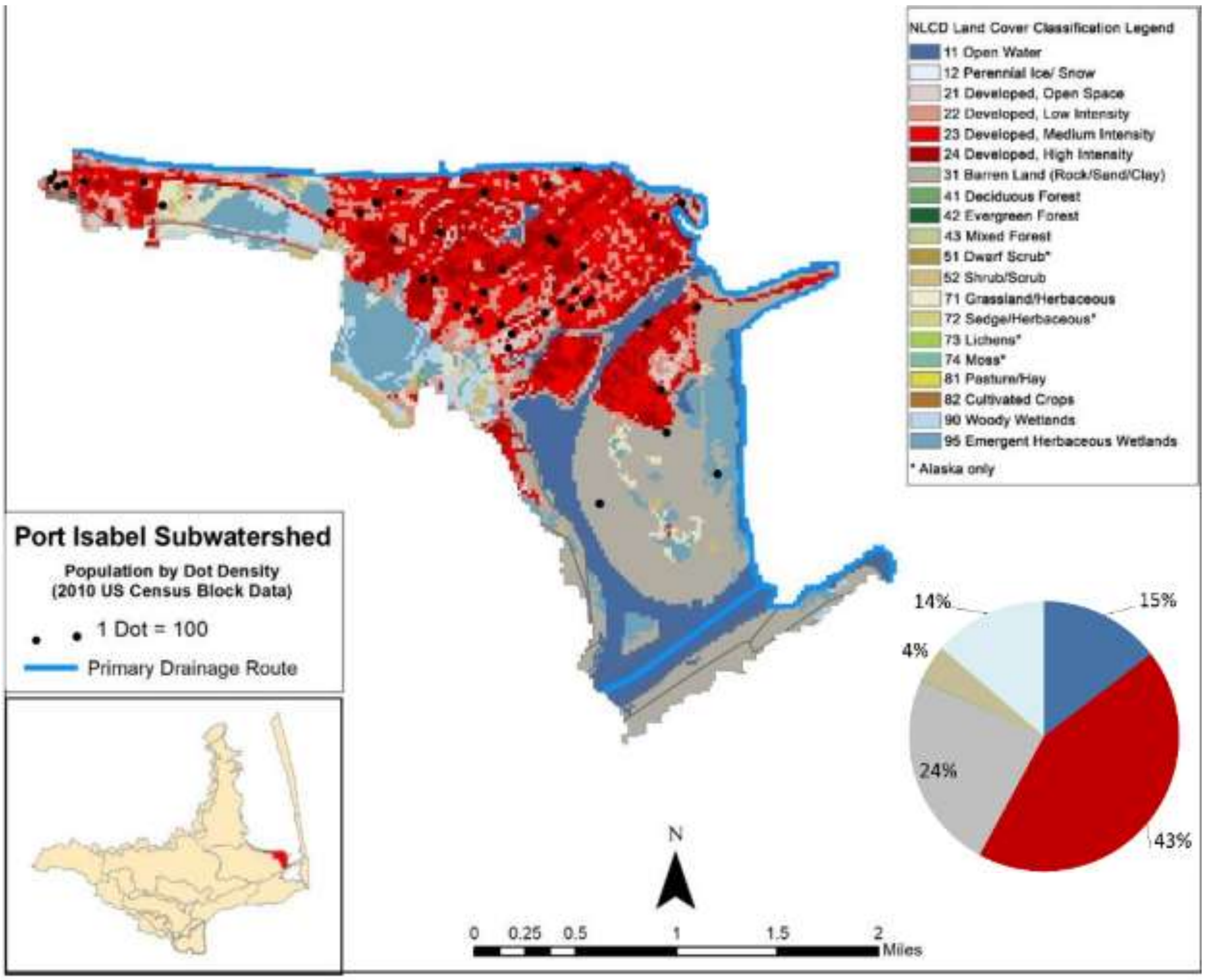


Figure 2-17. Port Isabel Subwatershed (Land Cover, Population Density, and Waterways)

2.4.6 South Padre Island Subwatershed

The South Padre Island Subwatershed was divided into two sections: upper (north) and lower (south) – in order to avoid the cumbersome and confusing "south" South Padre Island. The upper section was delineated specifically for the purpose of including the undeveloped portion of this important barrier island in the LLM / BSC study area. It is almost totally uninhabitated and is almost 80% barren sand dunes and natural barrier island / beachfront (east) / Bayfront (west). This section is 14.5 mi^2 in size and is bounded to the south by Andy Bowie Park and to the north by a point about 13 miles south of the Port Mansfiled Channel cut – a location just across the LLM from the Arroyo Colorado outlet (Figure 2-18).

The lower section of the South Padre Island Subwatershed was identified as the urbanized portion of the island covering the 6 mile long, 3.3 mi^2 area of island between Andy Bowie and Isla Blanca Parks to the Brazos Santiago Pass. This area is populated about 3 to 4 thousand year-long residents; however, the number of people on this island can vary considerably with holiday and tourist seasons ranging upward of 100 to 200 thousand people. The area is 61% medium to high-intensity urban development with about 18% barren land and a small (9%), but growing coastal wetland / marsh area dominated by mangroves and salt-tolerant plants.

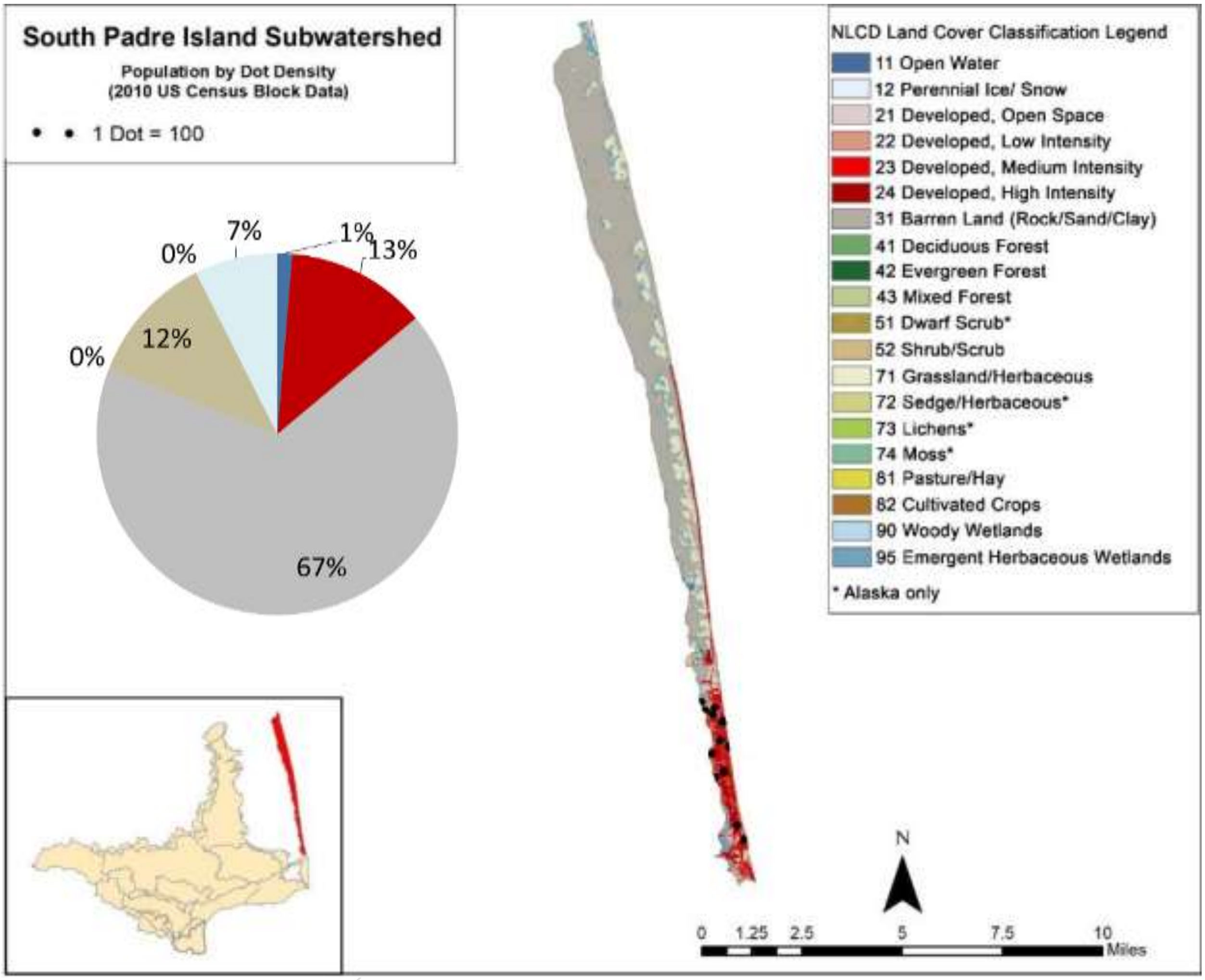


Figure 2-18. South Padre Island Subwatershed (Land Cover, Population Density, and Waterways for both Upper and Lower Sections)

Table 2-1: Land Cover and population summarized by subwatershed

Subwatershed	Area	Population	Population Density	Majority Land Cover and %	Type
Town Resaca	5.6 (%)	29,000	5,145	Developed (93%)	Stormwater Dominated Resaca
North Main Drain	11.1	43,000	3,900	Developed (78%)	Primary / Secondary Drainage
Resaca de la Palma / Guerra (Both)	16	17,300	1,079	Agriculture (38%)	Resaca System
RDLG – U/S	11.9	3,000	256	Agriculture	Resaca System – Sink

				(50%)	
RDLG – D/S	4.1	14,300	3,440	Developed (75%)	Resaca System – Augmented Flow
CCDD#1	25.8	76,155	2,955	Developed (70%)	Primary / Secondary Drainage
Resaca del Rancho Viejo (All)	51.2	22,900	447	Agriculture (54%)	Resaca System
RRV – U/S	36.4	12,700	348	Agriculture (60%)	Resaca System - Sink
RRV – M/S	9.3	2,700	289	Agriculture (51%)	Resaca System – Augmented Level
RRV – D/S	5.5	7,500	1,360	Developed (39%)	Resaca System – Augmented Level
San Martin (CCDD#2 and #3)	93	20,300	213	Wetlands (38%)	Primary / Secondary Drainage
Resaca de los Cuates (Both)	30	3,850	127	Agriculture (34%)	Resaca System
RDLC – U/S	16.5	3,600	216	Agriculture (47%)	Resaca System – Augmented Flow
RDLC – D/S	13.5	250	19	Wetland (39%)	Resaca System – Coastal / Sink
Southmost Drain	13.1	12,000	915	Agriculture (46%)	Primary / Secondary Drainage – Tile Drain
Loma Alta	18	2,000	107	Wetland (40%)	Primary / Secondary Drainage
Port of Brownsville	30.8	600	28	Barren Land (32%)	Coastal – Ship Channel Proper
Bahia Grande / Vadia Ancha	39	0	0	Barren Land (36%)	Coastal – Ship Channel
Lower Laguna Madre	62	6,800	106	Wetlands (37%)	Coastal
South Bay	26	16	0.6	Wetlands (51%)	Coastal
Port Isabel	4.4	6,300	1,400	Developed (43%)	Coastal
South Padre Island (Both)	17.8	2,900	157	Barren Land (67%)	Coastal
SPI – Upper	14.5	0	0	Barren Land (78%)	Coastal
SPI – Lower	3.3	2,900	850	Developed (61%)	Coastal

3 POINT SOURCES AND SEPTIC SYSTEMS

Potential sources of pollution can be divided into two primary categories: regulated and unregulated. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

Permitted sources are regulated by permit under the TPDES and the NPDES programs. WWTF outfalls and stormwater discharges from industries, construction, and MS4s represent the permitted sources in the LLM/BSC watershed.

3.1 NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMITS

Currently there are 13 domestic permitted wastewater outfalls, 1 groundwater desalination wastewater outfall, and 5 industrial wastewater outfalls with TPDES/NPDES permits that operate within the LLM/BSC watershed (Table 3-1 and Figure 3-1). <Add some discussion><Desalination info too>

Table 3-1. Permitted domestic, industrial, and desalination wastewater facilities.

Map #	NPDES	Facility Registry Service ID	Permittee	Facility	Discharge Type	Permit limits	Permit MGD	1st Receiving Water Body
1	TX0071340	110064600944	Brownsville PUB	Robindale WWTF	Domestic	20/20/4	14.5	San Martin Lake
2	TX0055484	110054917051	Brownsville PUB (Southmost Regional Water Authority)	SRWA RO	Desalination	16,704 (TDS Only)	4.0	San Martin Lake
3		TX0023639	Laguna Madre Water District	Isla Blanca WWTF	Domestic	10/15	2.6	Laguna Madre
4	TX0023621	110009745838	Laguna Madre Water District	Andy Bowie WWTF	Domestic	10/15/3	1.5	Laguna Madre
5	TX0023647	110000502849	Laguna Madre Water District	Port Isabel WWTF	Domestic	10/15/3	1.1	Laguna Madre
6	TX0091243	110006801032	City of Los Fresnos	City of Los Fresnos WWTF	Domestic	10/15/3	1.0	San Martin Lake
7	TX0117072	110009772629	Laguna Madre Water District	Laguna Vista WWTF	Domestic	10/15/3	0.65	Laguna Madre
8	TX0123498		Military Highway WSC	Joines Road Regional WWTF	Domestic	20/20/3	0.51	Rancho Viejo
9	TX0113875	110009773272	Olmito WSC	Olmito WSC Los Fresnos WWTF	Domestic	10/15/5	0.75	San Martin Lake
10	TX0127833		Valley MUD No. 2	Rancho Viejo WWTF	Domestic	10/15/3	0.40	San Martin Lake
11		110052414482	Valley MUD #2 Rancho Viejo Groundwater Reverse Osmosis	Rancho Viejo RO	Desalination (No surface discharge)	NA	NA	NA
12	TX0100242	110009774789	Brownsville Navigation District (Marine Cargo Handling)	Fishing Harbor WWTP	Industrial	20/20	0.25	Ship Channel
13	TX0056821	110006683561	U.S. Dept of Homeland Security Immigration and Customs Enforcement	Bayview Detention Center WWTF	Domestic	20/20	0.16	Laguna Madre
14	TX0074047	110062510466	Brownsville Navigation District	Turning Basin WWTF	Domestic	20/20	0.10	Ship Channel
15	TX0134899	110058931571	East Rio Hondo WSC	Southside WWTF	Domestic	10/15	0.10	San Martin Lake
16	TX0006564	110006683455	Brownville Navigation District	Northside WWTF	Domestic	20/20	0.098	Ship Channel
17	TX0136689	110012534800	Texas Pack Inc (Food Manufacturing)	Port Isabel	Industrial	2018 Average = 0.15MGD		Laguna Madre
18	TX0137308	110070067369	Maverick Fuel Oil Terminal (Petroleum Refining)	Ship Channel	Industrial	2018 Average = 0.0184MGD		Ship Channel
19	TX0137316	110070067370	Brownsville Fuel Oil Terminal (Petroleum Refining)	Ship Channel	Industrial	2018 Average = 0.045MGD		Ship Channel
20	TX0087441	110002050725	KAAPA Aqua Ventures Alliance LLC (Animal Aqua Culture)	Kava Farms	Industrial	2018 Average = 0MGD		Laguna Madre

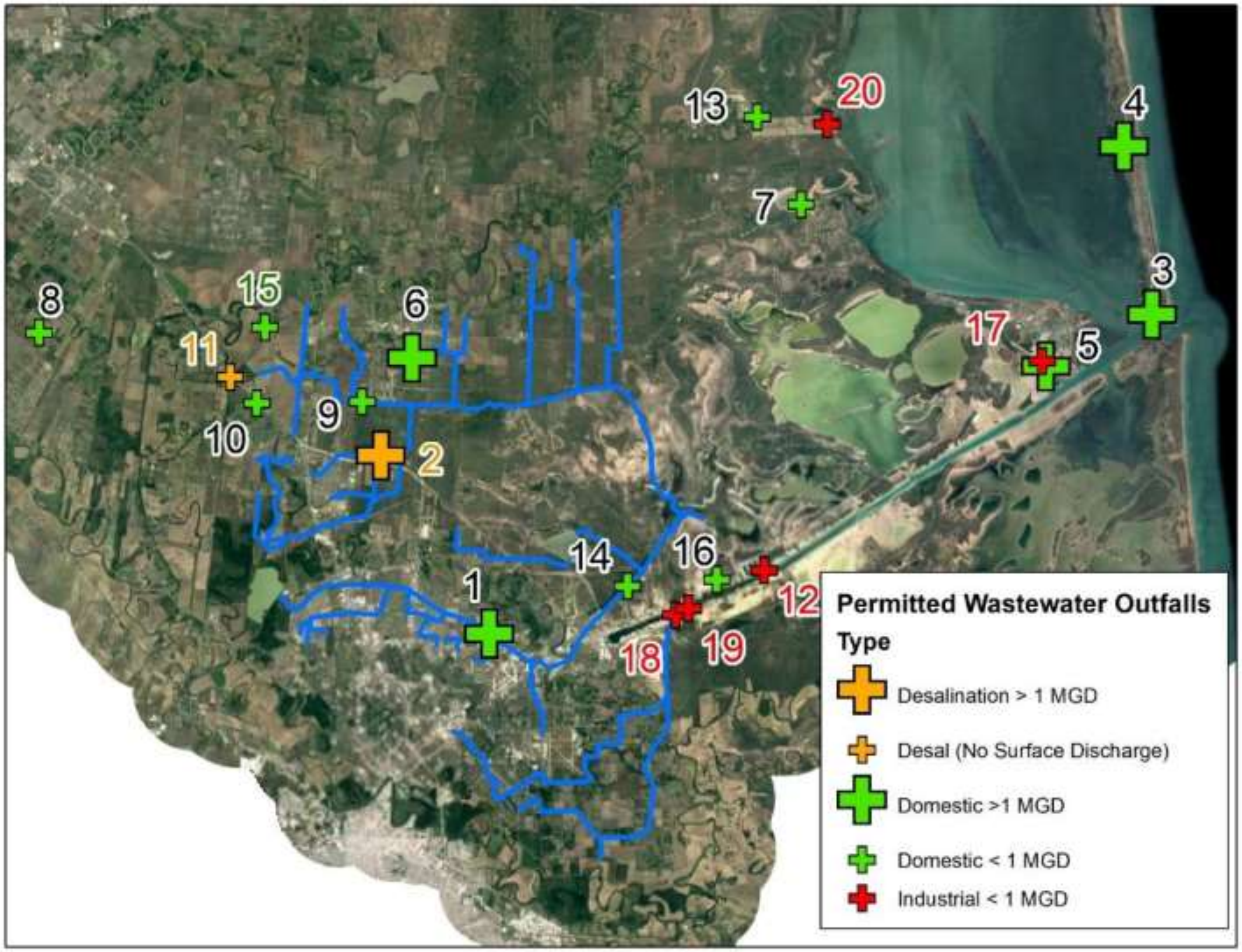


Figure 3-1. Wastewater treatment facilities and their permitted discharge (MGD) in the LLM/BSC watershed.

3.2 Cameron County Septic System Inventory

Private residential on-site sewage facilities (OSSFs), commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above ground sprinkler system for distributing the liquid. In this watershed, 95% of the OSSFs installed are septic tanks with a drain field. In simplest terms household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the waste flows to the distribution system which may consist of buried perforated pipes or an above ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weikel et al., 1996).

During the development of the Arroyo Colorado WPP and the Texas Coastal Zone OSSF Inventory, Texas AgriLife Extension and TWRI a preliminary effort was conducted to estimate OSSFs. TWRI and Extension acquired sewer service maps from cities and other sewer providers and digitized polygons of the sewer service areas. Cameron County 911 addresses were obtained and addresses outside the service areas were assumed to utilize an OSSF. & Cameron County. Preliminary estimate maps were created for both the Arroyo Colorado watershed and the Coastal Zone. TWRI, UTRGV, and Extension then partnered to develop a more detailed inventory and database of OSSFs.

For the second Phase of the OSSF Inventory, TWRI, UTRGV, and Texas AgriLife Extension are working with Cameron County to develop an inventory of all OSSFs within Cameron County. The project team entered into a collaborative agreement between Cameron County and TWRI, Texas A&M AgriLife Extension & UTRGV to review the counties OSSF permit data in order to identify and estimate the total number of OSSFs in the watershed. The project team obtained permit spreadsheets and records and was able to automatically match some permits to the Cameron County Appraisal District Parcel GIS layer. The project team was also able to match permits that contained addresses to the Cameron County 911 GIS layer. So far approximately 10,000 OSSF permit files have been automatically matched to the Parcel and 911 GIS layers. Figure 3-2 is a map showing parcel centroids and 911 addresses of the matched permits. There are many additional permits that will need to be manually matched to the GIS parcel layer. This next phase of the project is about to begin and will accomplish this.

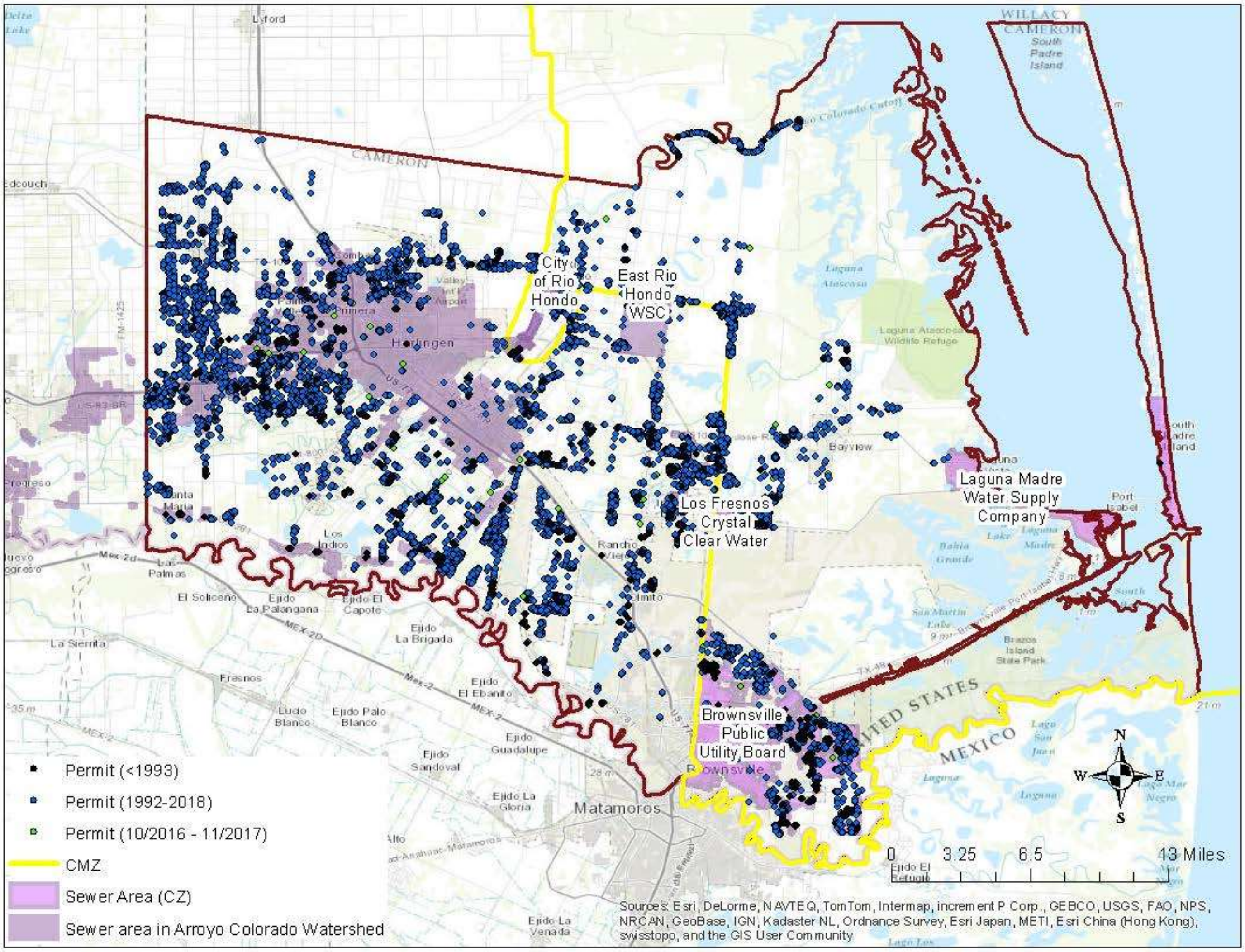


Figure 3-2. Cameron County OSSF permits geolocated through August 2018.

3.3 Municipal Separate Storm Sewer System Permits

A distinction must be made between stormwater originating from an area under a TPDES or NPDES regulated discharge permit and stormwater originating from areas not under a TPDES or NPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1) stormwater subject to regulation, which is any stormwater originating from TPDES-regulated Phase I and Phase II MS4 areas, stormwater associated with concentrated animal feeding operations (CAFOs), stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and

2) stormwater runoff not subject to regulation.

The TPDES/NPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities within an EPA-defined urbanized area that are regulated by a general permit. The purpose of a MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention/good housekeeping.

The geographic region of the watersheds covered by Phase I and II MS4 permits is that portion of the area within the jurisdictional boundaries of the regulated entity. For Phase I permits the jurisdictional area is defined by the city limits and for Phase II permits the jurisdictional area is defined as the intersection or overlapping areas of the city limits and the 2000 or 2010 Census Urbanized Area.

Table 3-2. MS4 permits discharging to Ship Channel (Segment 2494)

Auth #	Permittee	Site Location
TXR040236	CAMERON COUNTY DRAINAGE DISTRICT 1	SOUTHEAST CAMERON COUNTY FROM THE RESACA DE LOS CUATES TO THE RIO GRANDE RIVER FLOOD LEVEE AND WITHIN THE BROWNSVILLE URBANIZED AREA
TXR040264	CITY OF BROWNSVILLE	THE MS4 REGULATED BOUNDARIES OF CITY OF BROWNSVILLE IS WITHIN THE BROWNSVILLE URBANIZED AREA AND ALL AREAS WITHIN THE CITYS JURISDICTION INCLUDING ITS URBAN EXTRA TERRITORIAL JURISDICTION
TXR040270	CITY OF LOS FRESNOS	AREA WITHIN THE CITY OF LOS FRESNOS LIMITS THAT IS LOCATED WITHIN THE BROWNSVILLE URBANIZED AREA
TXR040537	VALLEY MUD 2	AREA WITHIN THE TOWN OF RANCHO VIEJO & PARTIALLY LOCATED WITHIN THE CITY OF BROWNSVILLE LIMITS THAT IS WITHIN & OUTSIDE THE BROWNSVILLE URBANIZED AREA

Table 3-3. MS4 permits discharging to Lower Laguna Madre (Segment 2491_03)

Auth #	Permittee	Site Location
TXR040236	CAMERON COUNTY DRAINAGE DISTRICT 1	SOUTHEAST CAMERON COUNTY FROM THE RESACA DE LOS CUATES TO THE RIO GRANDE RIVER FLOOD LEVEE AND WITHIN THE BROWNSVILLE URBANIZED AREA
TXR040264	CITY OF BROWNSVILLE	THE MS4 REGULATED BOUNDARIES OF CITY OF BROWNSVILLE IS WITHIN THE BROWNSVILLE URBANIZED AREA AND ALL AREAS WITHIN THE CITYS JURISDICTION INCLUDING ITS URBAN EXTRA TERRITORIAL JURISDICTION
TXR040270	CITY OF LOS FRESNOS	AREA WITHIN THE CITY OF LOS FRESNOS LIMITS THAT IS LOCATED WITHIN THE BROWNSVILLE URBANIZED AREA
TXR040051	CAMERON COUNTY	AREA WITHIN JURISDICTION OF CAMERON COUNTY AND LOCATED WITHIN THE BROWNSVILLE AND HARLINGEN URBANIED AREAS

4 WATER QUALITY

4.1 TEXAS WATER QUALITY STANDARDS AND INTEGRATED REPORT

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific users. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards, and publishes the *Texas Water Quality Integrated Report* list biennially.

The *Texas Surface Water Quality Standards* (TSWQS; TCEQ, 2018) are rules that:

- designate the uses, or purposes, for which the state's water bodies should be suitable;
- establish numerical and narrative goals for water quality throughout the state; and
- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the TSWQS to water bodies are:

- aquatic life use
- contact recreation

- domestic water supply
- general use

Fecal indicator bacteria (FIB) are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Both *E. coli* (*Escherichia coli*) and *Enterococcus* spp. are present in the intestinal tracts of humans and other warm blooded animals. The presence of these bacteria in water indicates that associated pathogens from the wastes that may be reaching water bodies as a result of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). *E. coli* is widely used as an indicator in freshwater, while Enterococci are more often used as an indicator in high saline inland waters and seawater. *E. coli* (*Escherichia coli*) and *Enterococcus* spp are both relevant FIB for the LLM/BSC watershed.

After coordination with stakeholders and advisory workgroup meetings, the TCEQ adopted revisions to the standards on February 7, 2018. The proposed standards were published in the Texas Register on September 8, 2017, and a public hearing was conducted on October 16, 2017. The adopted TSWQS revisions were published in the Texas Register on February 23, 2018, and the revised rules have an effective date of March 1, 2018. The adopted standards revisions have been submitted to Environmental Protection Agency (EPA) for review and approval.

For freshwater, recreational use consists of five categories:

- Primary contact recreation 1 is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean (geomean) criterion for *E. coli* of 126 most probable number (MPN) per 100 mL and a single sample criterion of 399 MPN/100 mL;
- Primary contact recreation 2 is similar to primary contact 1, but activities occur less frequently due to physical characteristics of the water body or limited public access. It has a geomean criterion of *E. coli* of 206 MPN/100Ml;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geomean criterion for *E. coli* of 630 MPN/100 mL;
- Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently due to physical characteristics of the water body or limited public access. It has a geomean criterion for *E. coli* of 1,030 MPN/100 mL; and
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geomean criterion for *E. coli* of 2,060 MPN/100 mL.

For saltwater, recreational use consists of three categories:

- Primary contact recreation 1 is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean (geomean) criterion for *Enterococcus* of 35 most probable number (MPN) per 100 mL and a single sample criterion of 130 MPN/100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geomean criterion for *Enterococcus* of 175 MPN/100 mL;

- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geomean criterion for *E. coli* of 350 MPN/100 mL.

There are eight assessment units (AUs) represented by 28 surface water quality monitoring (SWQM) stations in draft TCEQ's 2016 Integrated Report. Table 4-1 below displays the stations associated with the Texas water quality assessment in each AU plus station 14857 (AU 2493_01) which is included in analyses within this report because of its relatively robust dataset.

Table 4-1. Assessment units in the LLM/BSC watershed

AU	SWQM Station	TCEQ Description	Type	2016 Impairment
2491_02	13447[a]	**Area adjacent to the Arroyo-Colorado confluence**	Estuary	Bacteria; DO
2491_03	14844	**Lower portion of bay** south of the Arroyo-Colorado confluence	Estuary	None
	14845			
	14870			
	14869			
	14861			
	14862			
	14863			
	13446			
	14876			
	17100			
	14868			
	14878			
	14879			
	17975			
	14877[b]			

AU	SWQM Station	TCEQ Description	Type	2016 Impairment
2491C_01	None	**Minor Drainage Ditches flowing into Segment 2491** (unclassified water body)	Freshwater	None
2493_01	14857[c] 14858 14865 14856 17101 14855 14880 13459	**South Bay** (entire segment)	Estuary	None
2494_01	14871 14875 13460 17102	**Brownsville Ship Channel** *From the Laguna Madre confluence upstream to the Port of Brownsville*	Estuary	Bacteria
2494A_01	13285	**Port Isabel Fishing Harbor** (unclassified water body) *From the Laguna Madre confluence to 0.4 km (.25 mi) south of SH 100 in Port Isabel*	Estuary	Bacteria
2494B_01	None	**Main Drainage Ditches flowing into Segment 2494** (unclassified water body)	Freshwater	None
2494B_02	None	**Minor drainage ditches flowing into Segment 2494 (unclassified water body)**	Freshwater	None

AU	SWQM Station	TCEQ Description	Type	2016 Impairment
2494C_01 [d]	None	**San Martin Lake** (unclassified water body) *From confluence of 2494B diches to outlet at 2494*	Estuary	None

[a] This station is located at the extreme north end of the study area and likely is more representative of the Arroyo-Colorado watershed than the AUs of interest.

[b] Station 14877, although used in the 2012 integrated report for 2491_03, is located more south in the South Bay than Station 13549, the principal sampling site in South Bay.

[c] Not used in Assessment but included in analyses because of relatively robust dataset.

[d] Draft 2018 Texas Integrated Report.

In addition to bacteria, streams, estuaries, and reservoirs in Texas are monitored for nutrient enrichment. Water bodies not specified in the TSWQS for specific chlorophyll-a criteria are protected from excessive nutrient levels in order to support the general uses through the use of screening levels. The screening levels listed for nutrients and chlorophyll-a were statistically derived from SWQM monitoring data at the 85th percentile value and are used when site specific criteria have not been developed in the TSWQS. The screening level concentrations for each nutrient parameter are described in Table 4-2. A concern for water quality is identified if the screening level is exceeded in greater than 20 percent of the samples using the binomial method which is based on the number of exceedances for a given sample size. Screening levels are discussed in this report simply as a point of reference, not for assessment purposes.

Table 1-2. Nutrient screening levels for Texas estuaries. Source: TCEQ (2016).

Water Body Type	Nutrients	Screening Level
Freshwater Stream	NH_3-N NO_3-N OP TP Chl *a*	0.33 mg/L 1.95 mg/L 0.37 mg/L 0.69 mg/L 14.1 µg/L
Reservoir	NH_3-N NO_3-N OP TP Chl *a*	0.11 mg/L 0.37 mg/L 0.05 mg/L 0.20 mg/L 26.7 µg/L
Tidal Stream	NH_3-N NO_3-N OP TP Chl *a*	0.46 mg/L 1.10 mg/L 0.46 mg/L 0.66 mg/L 21.0 µg/L
Estuary	NH_3-N NO_3-N OP TP Chl *a*	0.10 mg/L 0.17 mg/L 0.19 mg/L 0.21 mg/L 11.6 µg/L

4.2 TEXAS ROUTINE COORDINATED MONITORING SITES

The TCEQ Surface Water Quality Monitoring Program and the Clean Rivers Program conduct routine monitoring throughout the state of Texas. Through this program, active stations are monitored quarterly and data collection includes field and conventional parameters at a minimum. Selected stations are also monitored for bacteria, flow, toxic compounds, metals and toxicity.

Water quality data collected at these sites are stored in the state's SWQM database and available online. Data in this database provide information used by TCEQ in its biennial statewide water quality assessments, which use a seven-year moving window of time to ensure that recent water quality is adequately reflected. Assessments are conducted to ensure that water bodies comply with water quality criteria specified in the Texas Surface Water Quality Standards.

Current monitoring in the LLM/BSC watershed consists of 9 routine sites, which are monitored quarterly. (Figure 4-1) Table 4-1 shows a summary of the current coordinated monitoring schedule. A schedule of routine monitoring is developed every state fiscal year. The most current coordinated monitoring schedule is located at this website https://cms.lcra.org/.

TIAER completed a complete historical analysis and data review of all data in the TCEQ SWMIS database and that analysis is included in Appendix B of this report.

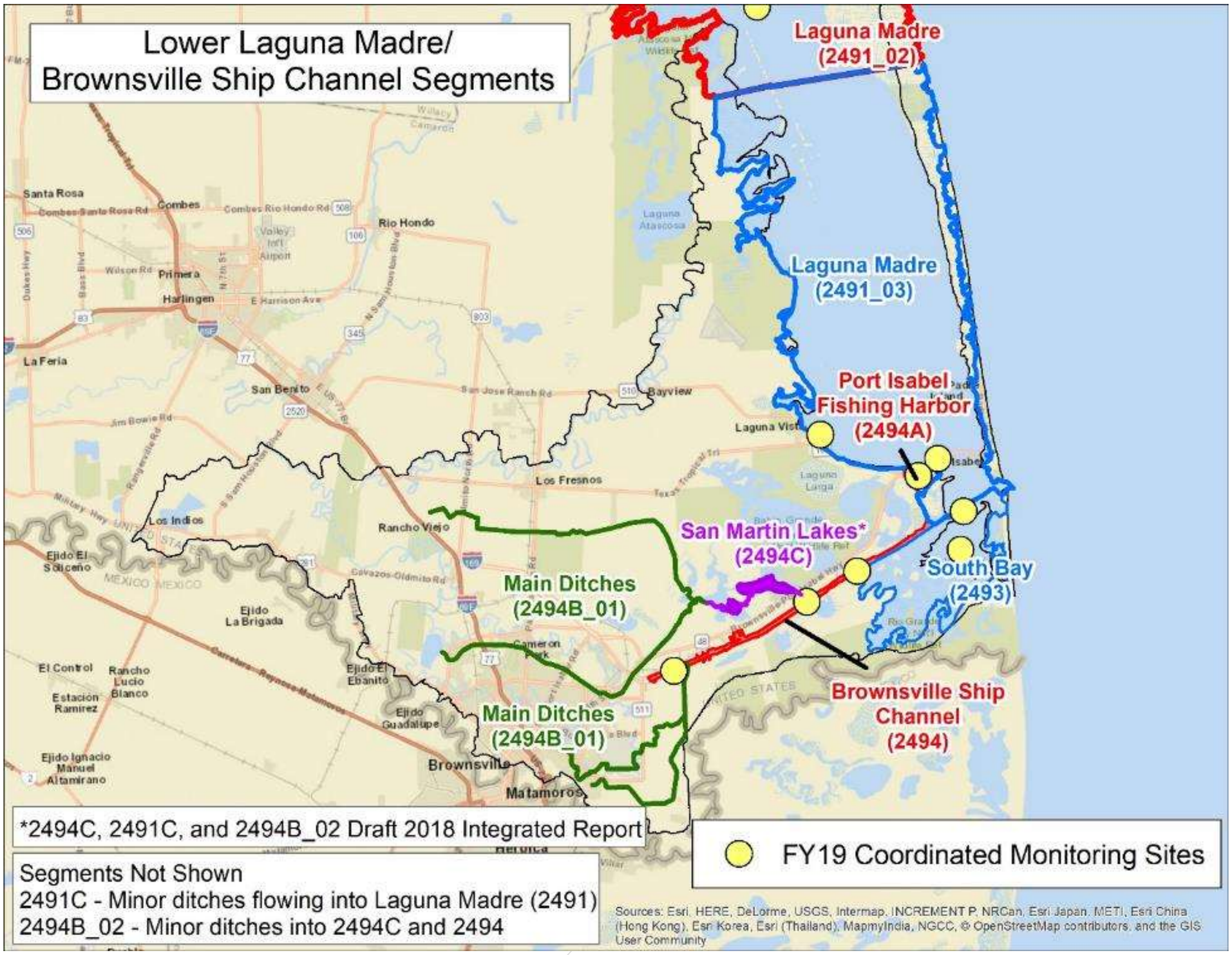


Figure 4-1: State Fiscal Year 2019 Coordinated Monitoring Sites.

Table 4-1: Description of sampling locations, parameters analyzed, sampling frequency and agency currently conducting water quality sampling in the LLM/BSC watershed.

Sample Location	Segment	Parameter	Frequency	Agency
14871 – Brownsville Ship Channel Mid Channel 595 miles east of state highway 48 at Foust Rd	2494	Conventional	4	TCEQ Region 15
		Field	4	
14875 – Brownsville Ship Channel mid channel at entrance to San Martin Lake	2494	Conventional	4	TCEQ Region 15
		Field	4	
13460 – Brownsville Ship Channel near Ship Channel Marker 35/Black Buoy	2494	Conventional	4	TCEQ Region 15
		Field	4	
13285 – Port Isabel Fishing Harbor, approximately 60 mi downstream of state highway 100 bridge	2494A	Conventional	4	TCEQ Region 15
		Field	4	
13459 – Laguna Madre South Bay Pass Approximately 0.1 km west of Clark Island	2493	Conventional	4	TCEQ Region 15
		Field	4	
14865 – South Bay Middle of Bay	2493	Conventional	4	TCEQ Region 15
		Field	4	
13446 – Laguna Madre Intracoastal Canal at Marker 129 East of Port Isabel	2491_03	Conventional	4	TCEQ Region 15
		Field	4	
14870 – Laguna Madre 200 yds off Laguna Vista Shoreline	2491_03	Conventional	4	TCEQ Region 15
		Field	4	
13447 – Laguna Madre intersection of Intracoastal Canal and Arroyo Colorado	2491_02	Conventional	4	TCEQ Region 15
		Field	4	
		Field	4	

(Source: CRP 2016 Coordinated Monitoring Schedule available at http://cms.lcra.org/).
Note: No *Enterococcus* samples have been collected since 2008 due to lab logistical issues.

4.3 UTRGV Bi-Monthly Monitoring

Summary of Field Data Collection Efforts for Water Quality Monitoring of the Brownsville Ship Channel and Lower Laguna Madre

In support of a watershed characterization effort on the Lower Laguna Madre / Brownsville Ship Channel watershed, the University of Texas Rio Grande Valley (UTRGV) research team conducted field sampling at 5 locations – 3 along the Brownsville Ship Channel and 2 in the Lower Laguna Madre area (November 2016 – August 2018) (See Figure 4-2). The primary focus of the sampling effort was to determine bacteria levels (Enterococcus), nutrient levels, and vertical profile data of conductivity, temperature, pH, and dissolved oxygen. Additional supporting data such as secchi disk, weather conditions, and public utilization of waterways for recreation was also collected. Enterococcus bacteria grab samples were collected and transported to the Brownsville Public Utilities Board (BPUB) Analytical Laboratory for isolation and enumeration. Nutrient grab samples were collected at each station and transported to Ana-Lab, Inc. for analysis. Vertical profiles along with total depth of the water column (midstream) were conducted at each sampling location using multi-parameter sondes (EXO-1's) calibrated and maintained by UTRGV researchers.

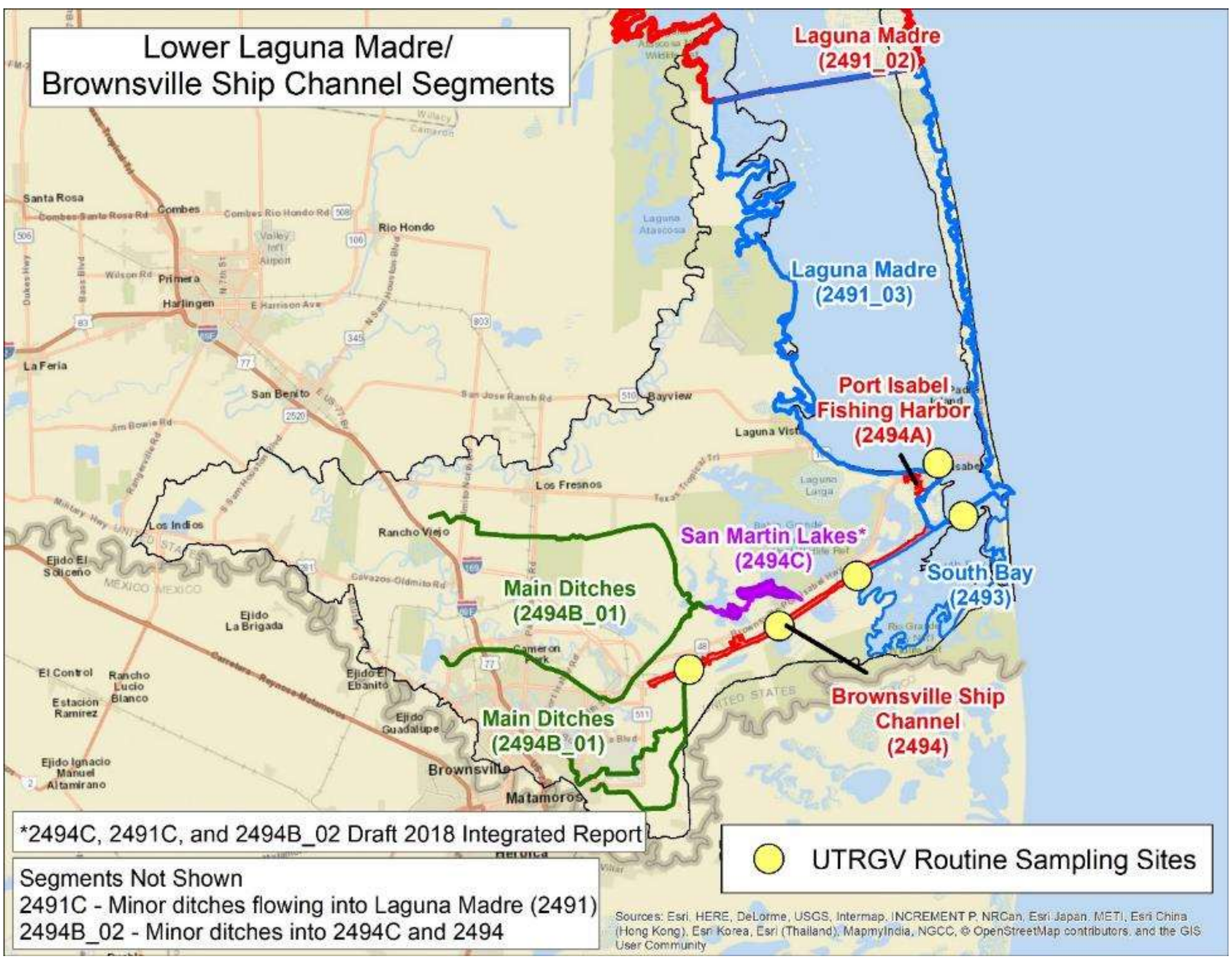


Figure 4-2: Locations of UTRGV sampling sites.

Table 4-2: Number of grab samples, vertical profiles, and streamflow measurements taken over the year (June 2014 – May 2015) at each of the approved 10 sampling stations along the Arroyo Colorado.

	13446	13459	13460	14874	14872
Bacteria Samples (Entero)	10*	10*	10*	7	7
Nutrient Grab Samples	12	12	12	7	7
Vertical Profile Data	12	12	12	7	7
Sampling Period (Bi-monthly)	Nov 2016-Aug 2018	Nov 2016-Aug 2018	Nov 2016-Aug 2018	Sept 2017-Aug 2018	Sept 2017-Aug 2018

* Nov 2016 and Jan 2017 bacteria samples were not reported due to improper analysis technique.

Table 4-2 illustrates the number of samples / measurements taken at each station over the near two year-long sampling period. Samples were taken bi-montly (every two months). Stations 13446, 13459, 13460 were the original three sampling locations at the start of the sampling effort; however, the first two bacteria samples were rejected due to the failure to properly dilute the sample volume by a factor of 10 to account for sampling in coastal waters. As such, only 10 bacteria samples were recorded and reported to SWQMIS from March 2017 – August 2018. Nutrient grab samples and vertical profiles were taken at these three stations over the entire sampling period – start date of November 2016. Stations 14874 and 14872 were added to the station monitoring list in September of 2017. An additional sample for all stations was taken during the last month – August 2018.

This section will summarize the methodologies used in collecting grab samples and field measurements, as well as provide a concise summary of resulting data. Specifically, the report will show and briefly discuss the bacterial enumerations (counts) for Enterococcus; a summary of vertical profile data; and a summary of nutrient data collected at each station.

METHODOLOGY

Sample Collection, Storage and Delivery (Enterococcus and Nutrients)

Water quality grab samples for bacteria analysis were collected at bi-monthly intervals per the approved QAPP. The number of successfully collected samples per station is shown in Table 4-2. Water samples were collected directly from the channel or laguna (midway in the stream channel when appropriate) via sampling boat, with appropriate care to avoid surface microlayer of water and bottom sediment to ensure the sample was representative of water in the stream. Grab samples for analysis of Enterococcus were collected in 500 ml sterile bottles provided by BPUB. Samples were collected following procedures in the most recent version of the *TCEQ SWQM Procedures, Volume 1 (RG-415),* including proper storage in ice chests and delivery to the BPUB analytical laboratory within the required holding time. Samples were delivered well under 4 hours to permit sufficient time for laboratory analysis within the required 6 hour holding time window. Grab samples for nutrient analysis included collection of water samples for the following parameters: Total Phosphorous, Total Nitrate-Nitrite Nitrogen, Total Kjeldahl Nitrogen, and Chlorophyll-a. Nutrient samples were delivered per the approved QAPP to Ana-Lab, Inc.'s field office in Brownsville, Texas for analysis.

Vertical Profiles of Salinity, DO, pH, Water Temperature and Total Depth of Water

Vertical profiles of salinity, DO, pH, water temperature along with total depth of water were conducted each time a water quality grab sample was collected (See Table 4-2). These parameters were measured in situ with an EXO1 (Xylem / YSI) multiparameter 4-port water quality sonde with depth sensor. Data were recorded in field notes and transferred immediately to electronic format after returning to UTRGV. Pre and Post calibration of the field instrumentation was completed as required by the QAPP and modified accordingly after a September 2017 audit.

Number of Days Since Last Significant Rainfall

Historical rainfall data archived by the National Weather Service's Advanced Hydrologic Prediction Service (http://water.weather.gov/precip/) were reviewed by the PI (Benavides) each month after sampling was complete. These data were used to record the required days since last significant rainfall for analysis and recording purposes.

Data and Discussion – Vertical Profile data of Temperature, pH, Conductivity (Salinity), and Dissolved Oxygen

The results of the vertical profile data collected at the five sampling stations are presented in Figures 4-3 through 4-7.

<u>Brownsville Ship Channel Stations – 14872, 14874, 13460</u>

Sampling stations 14872, 14874, 13460 were located along the Brownsville Ship Channel. The BSC has a dredged depth of over 12 m and as a result, data were collected at the following depths as per SWQMIS sampling procedures: 0.3, 3, 6, 9, and 12 m. Final depths varied from about 12 m to nearly 13.5 meters. Final data points were collected at 0.3 m from the bottom depth if the depth was greater than 13 m.

Twelve vertical profiles were collected at station 13460 and seven were taken at stations 14872 and 14874. Data for conductivity were converted to Practical Salinity Units (PSU's) for the purpose of this report as these units are more commonly used for comparison purposes than specific conductivity. Salinity and temperature data for all three BSC stations were indicative of a water body without the presence of a strong temperature and salinity gradient with increasing depth. Only mild increases in salinity and mild decreases in temperature were noted with increasing depth (about 0.5 – 1.0 C decrease and about 1.5 – 2.0 PSU's increase on average from 0.3 m to deepest sampling depth of about 12-13 m).

Figures 4-3 through 4-5 illustrate the salinity and temperature data for each sampling period across the three ship channel stations. The graphs show the warm month data in red lines, the cold month data in blue lines, and overall all sample average data in green. Figures 4-3 through 4-5 also illustrate the DO values with depth using the same color indicators as for salinity and temperature; however, these figures also show the average warm month DO values at each station using a bold red line and the average cold month DO values using a bold blue line. Data comparisons across station location along the BSC show a very mild increase in salinity values from west to east (inland to coastline) along the BSC; however, the statistical significance of this small difference was not analyzed as part of this report. More moderate changes were noted with respect to the variation of dissolved oxygen with depth across all three stations. Near surface values of DO averaged about 6.7-6.8 mg/L across all three stations. Near bottom values of DO averaged about 4.9, 5.4, and 5.8 mg/L for stations 14872, 14874, and 13460 respectively. The lowest DO values were noted to be along the more western station of 14872 – particularly for the warmer months, with a notable July 2018 depth profile of DO at station 14872 nearing 3.0 mg/L. No single DO measurement at any of these stations (any depth) was recorded below 3.0 mg/L and the only average DO value below 4.0 mg/L was noted at the deepest (near 13 m) measurement for Station 14872.

<u>Lower Laguna Madre Stations –13446 (near Isabella Causeway just west of the Intercoastal Waterway) and 13459 (South Bay inlet)</u>

Sampling stations 13446 and 13459 were located in different portions of the Lower Laguna Madre. Both locations were significantly shallower than the BSC stations with depths ranging from 2 to 3 meters. As a result, vertical profile data were taken at the following depths: 0.3 m below the surface, 0.3 m from bottom depth, and a mid-point depth between these two values.

Twelve vertical profiles were collected at these two stations. There was no notable variation of any measured parameter with depth at these locations. Therefore, the three depth values were averaged and plotted on a single graph for each station. Figures 4-6 and 4-7 show the resulting data for each station. Salinity measurements were unremarkable, showing the slight hypersalinity the LLM routinely exhibits due to its high surface to volume ration, high evaporation rates, and lack of significant tidal exchange with the Gulf of Mexico. Temperature and dissolved oxygen values were also unremarkable with no values below critical values for dissolved oxygen both for single point values and average values. The lowest DO reading was during the July 2017 measurement, a depth averaged value of 4.8 mg/L for station 13446.

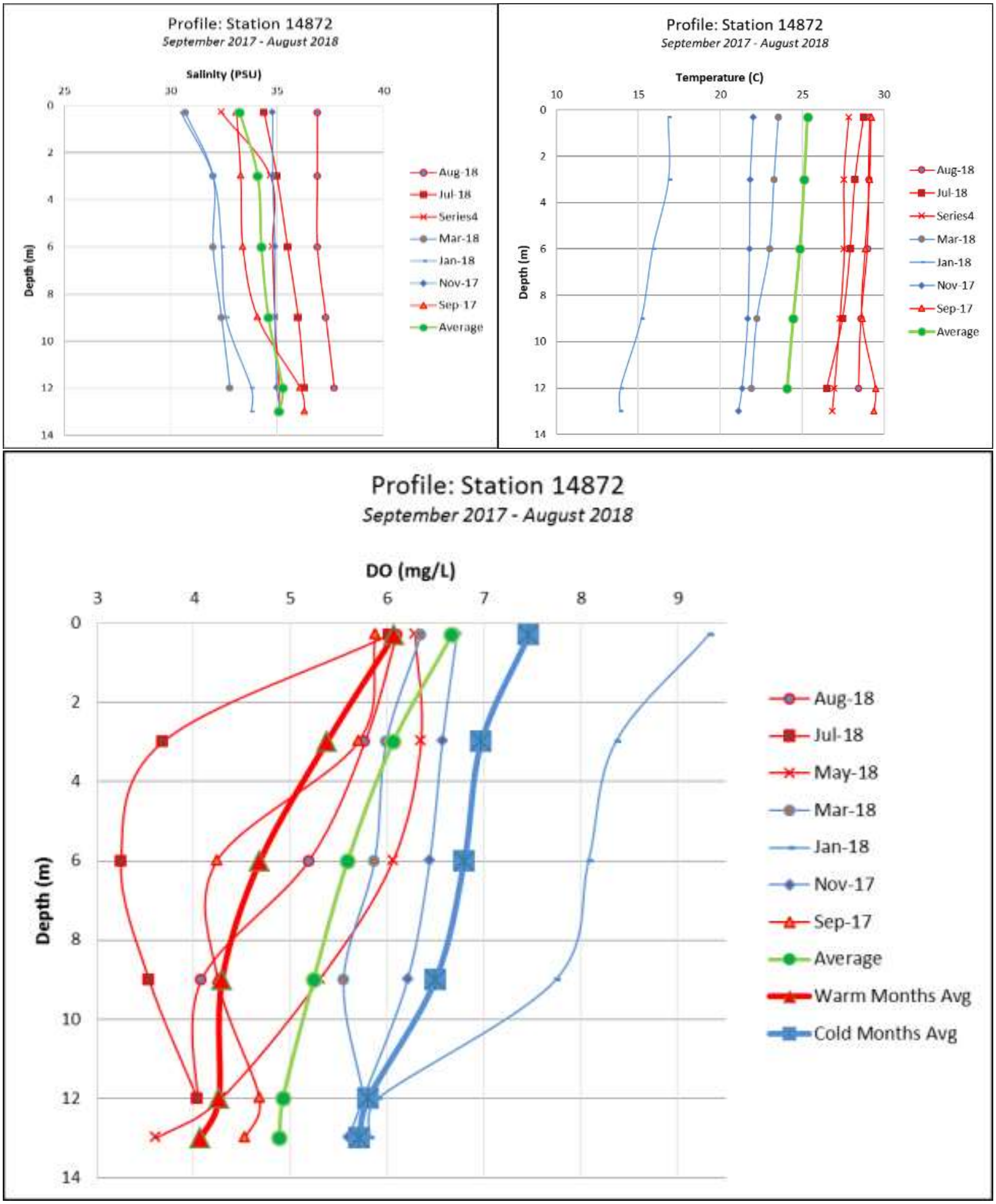


Figure 4-3: Vertical Profile Data of Salinity, Temperature and Dissolved Oxygen for Station 14872

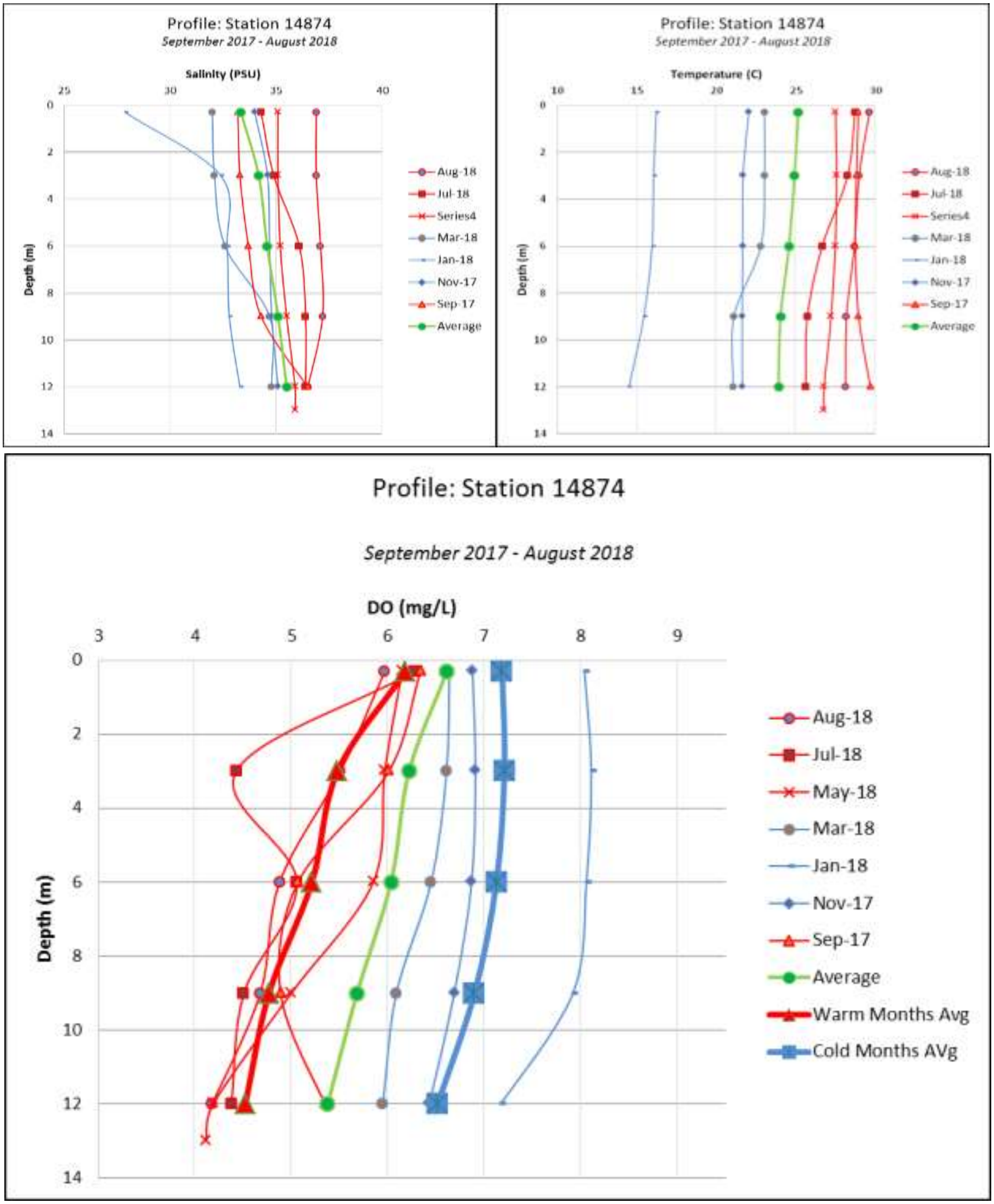


Figure 4-4: Vertical Profile Data of Salinity, Temperature and Dissolved Oxygen for Station 14874

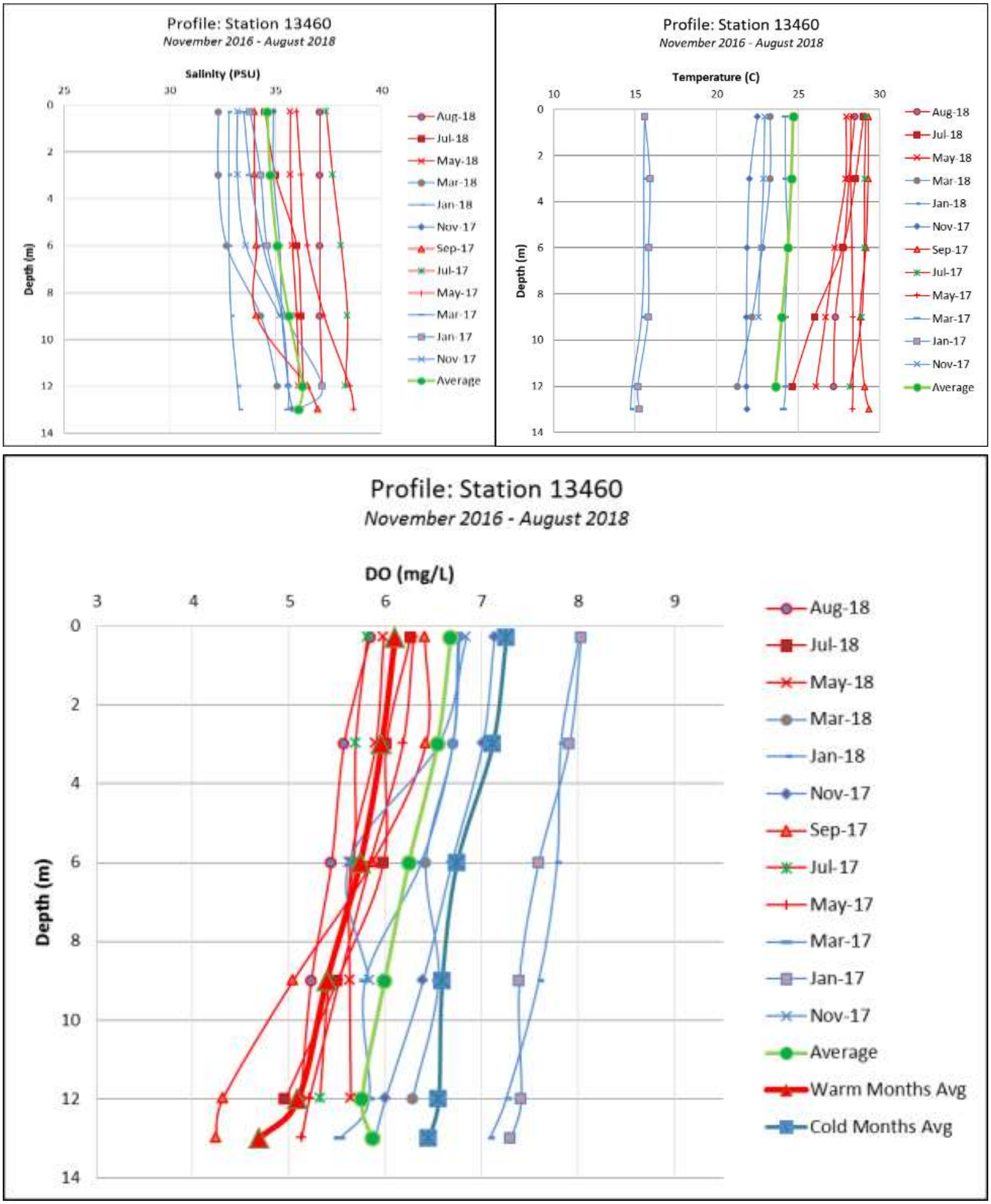


Figure 4-5: Vertical Profile Data of Salinity, Temperature and Dissolved Oxygen for Station 13460

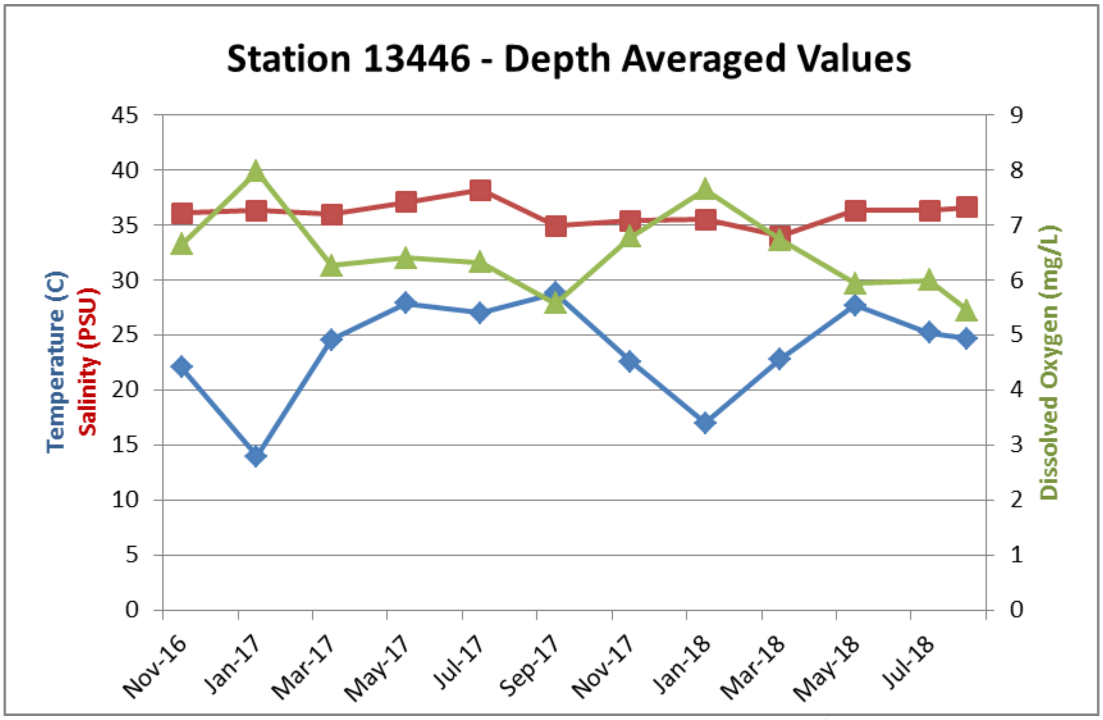


Figure 4-6: Depth Averaged Values for Vertical Profile Data at Station 13446

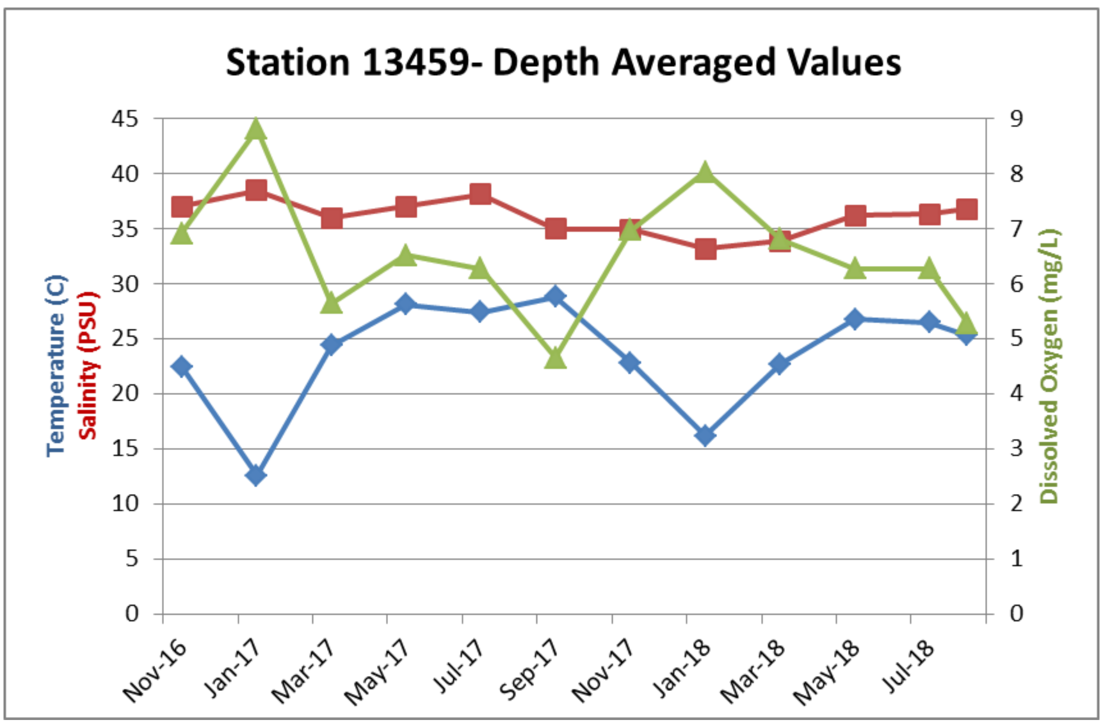
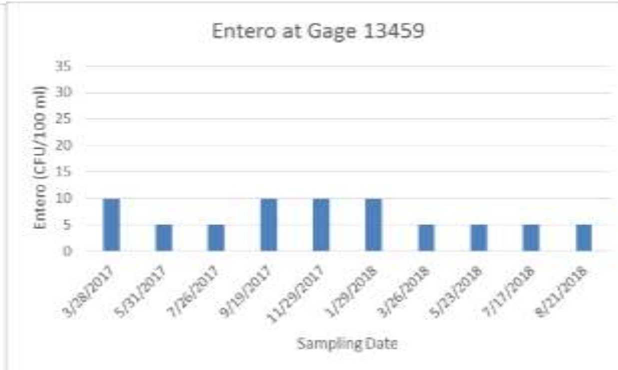


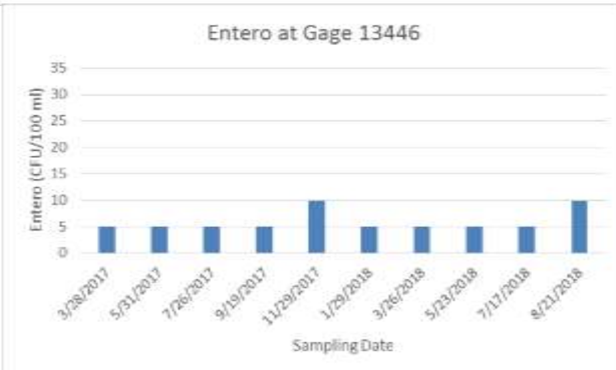
Figure 4-7: Depth Averaged Values for Vertical Profile Data at Station 13459

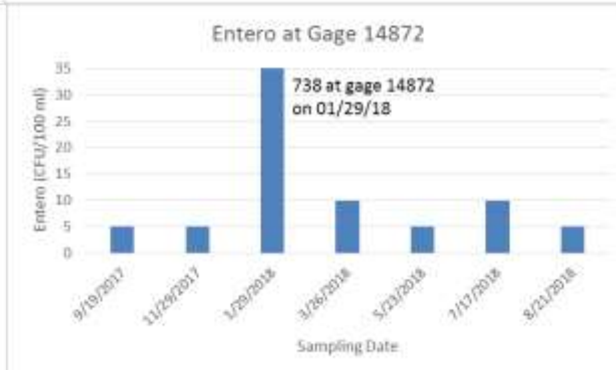
Data and Discussion – Enterococcus Data

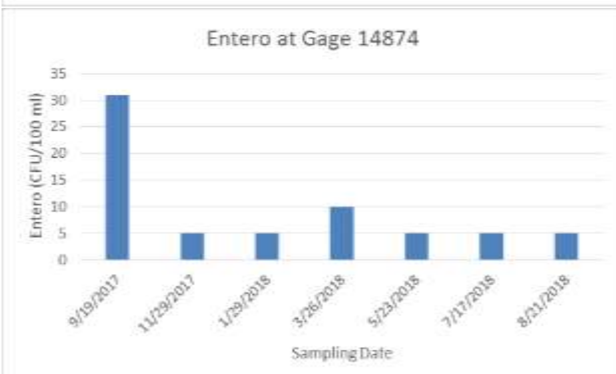
Five sampling stations were monitored over different time periods for enterococcus bacteria as per Table 4-2. Figure 4-8 shows results of the bacteria samples collected by UTRGV scientists and analyzed by the BPUB Water Quality Lab (NELAP certified). Enterococcus results were significant in that only one sample out of the 44 samples analyzed from all five stations violated the state standard for enterococcus in coastal waters. The geometric mean of samples taken at each station were calculated and shown. All station's geometric mean values were below state standards for enterococcus. Analyzed samples that had bacteria concentrations less than the reporting limit of 10 CFU / 100 mL were considered to have values of 5 CFU / 100 mL (citation required….) for the purpose of graphing and calculating geometric means. It should also be noted that there was no apparent trend with respect to bacteria levels and station location – aside from the fact that the only station that violated the standard (and a second that came close) were the western (more inland) stations 14872 and 14874.

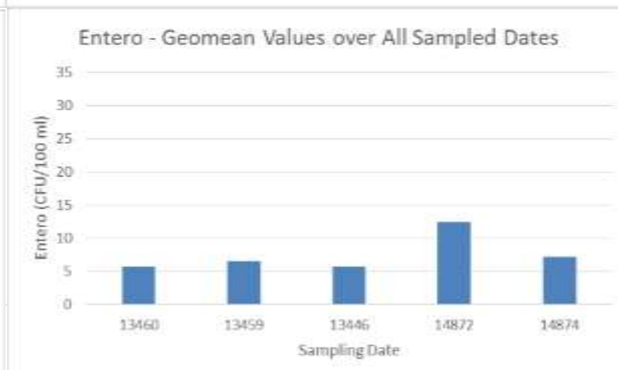

Entero at Gage 13460
Entero (CFU/100 ml)
3/28/2017
5/31/2017
7/26/2017
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
7/17/2018
8/21/2018
Sampling Date


Entero at Gage 13459
Entero (CFU/100 ml)
3/28/2017
5/31/2017
7/26/2017
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
7/17/2018
8/21/2018
Sampling Date


Entero at Gage 13446
Entero (CFU/100 ml)
3/28/2017
5/31/2017
7/26/2017
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
7/17/2018
8/21/2018
Sampling Date


Entero at Gage 14872
738 at gage 14872
on 01/29/18
Entero (CFU/100 ml)
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
7/17/2018
8/21/2018
Sampling Date


Entero at Gage 14874
Entero (CFU/100 ml)
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
7/17/2018
8/21/2018
Sampling Date


Entero - Geomean Values over All Sampled Dates
Entero (CFU/100 ml)
13460
13459
13446
14872
14874
Sampling Date

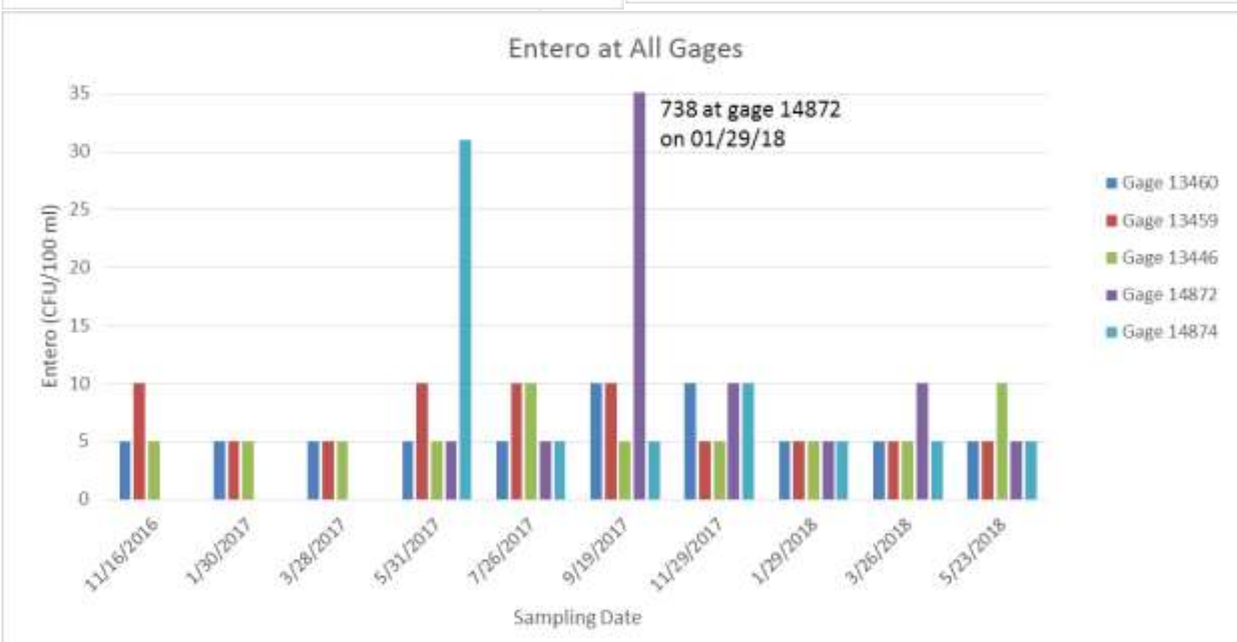

Entero at All Gages
738 at gage 14872
on 01/29/18
Entero (CFU/100 ml)
Gage 13460
Gage 13459
Gage 13446
Gage 14872
Gage 14874
11/16/2016
1/30/2017
3/28/2017
5/31/2017
7/26/2017
9/19/2017
11/29/2017
1/29/2018
3/26/2018
5/23/2018
Sampling Date

Figure 4-8: Enterococcus Data for Five Sampling Stations (including Geometric Mean Values for each Station and a Combined Station Graph for Comparison Purposes).

Data and Discussion – Nutrient Data

Five sampling stations were monitored over different time periods for nutrient parameters (Total Phosphorous, Nitrate-Nitrite Nitrogen, Total Kjeldahl Nitrogen) and chlorophyll-a per Table 4-2.

Figure 4-9 shows results of the nitrate-nitrite samples collected by UTRGV scientists and analyzed by Ana-Lab Inc. Nitrate-nitrite results were significant in that all five stations reported at least one sample exceeding 0.17mg/L. This level is the estuary screening level for Total Nitrate nitrogen for estuaries. Those sample results exceeding this value are illustrated in red. It should be noted that there was a notable trend with respect to station average samples for nitrate-nitrite nitrogen based on geographic location. Data show that values decrease from a high average of 0.27 mg/L for Station 14872 to a low average of 0.05 mg/L and 0.075 mg/L for Stations 13446 and 13459 respectively. The final August 2018 results showed a peculiar sample result of 15.6 mg/L for the usually low value reporting Station 13446. This may be considered an outlier based on the extremely high results (over two orders of magnitude higher than the average for the other 11 values). As such, it was removed from average calculations and is marked in orange.

Figure 4-10 shows results of the Total Kehldjahl samples collected by UTRGV scientists and analyzed by Ana-Lab Inc. Total K Nitrogen results were significant in that a similar trend to nitrate-nitrite nitrogen was exhibited with respect to station location. Total K Nitrogen decreased from inland to coastal. There is no available screening level for Total K nitrogen; however, station values, station averaged values, and time-series values for all stations are shown as for other parameters.

Figure 4-11 shows results of the Total Phosphorous (TP) samples collected by UTRGV scientists and analyzed by Ana-Lab Inc. TP results were significant in that all five stations reported at least one sample exceeding the estuary screening level of 0.21 mg/L. Those sample results exceeding this value are illustrated in red. Data show that higher station averaged values were observed for Stations 13459, 13469, and 14874. Stations 13459 and 13469 average values exceeded screening levels and stations 14874 was just under the screening level.

Figure 4-12 shows results of the chlorophyll-a samples collected by UTRGV scientists and analyzed by Ana-Lab Inc. Chlorophyll-a samples results were mostly below the screening level of 11.6 ug/L. One extremely high value (157 ug/mL) was noted at 13460 during the first sampling period in Nov 2016. There was a notable algal bloom present in the ship channel – the only one observed throughout the entire sampling period. Aerial photos of the ship channel were taken via drone and are available for review if requested. Given the presence of an algal bloom at the time, this value should not be considered an outlier in terms of concerns of the validity of the sample; however, it was not taken into consideration for station average values for the purpose of this report. Only one other value above the screening level was noted (Station 14872). There was again a notable trend with decreasing station average values from inland samples to seaward sampling station locations.

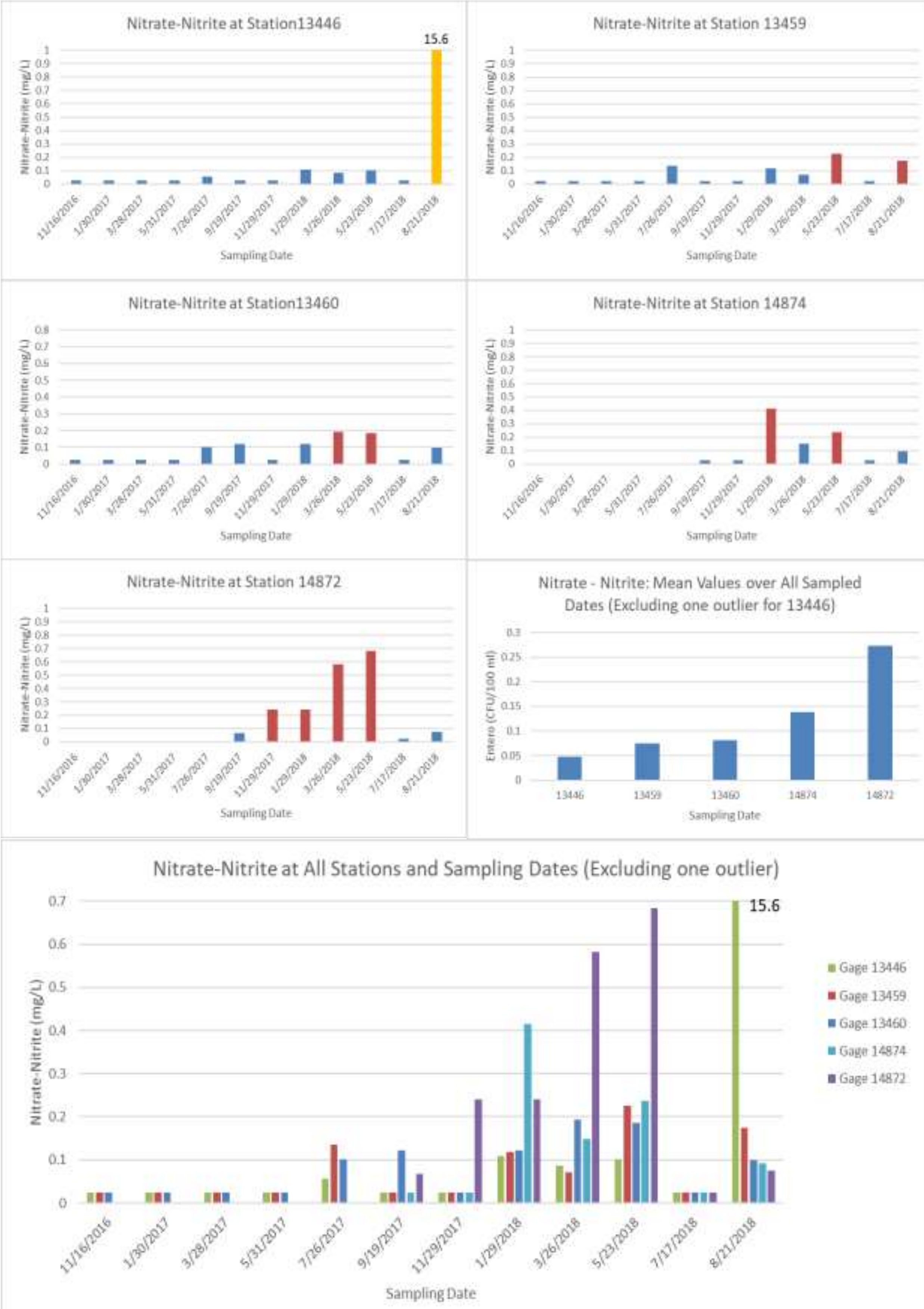


Figure 4-9: Nitrate-Nitrite Data for Five Sampling Stations (including Mean Values for each Station and a Combined Station Graph for Comparison Purposes).

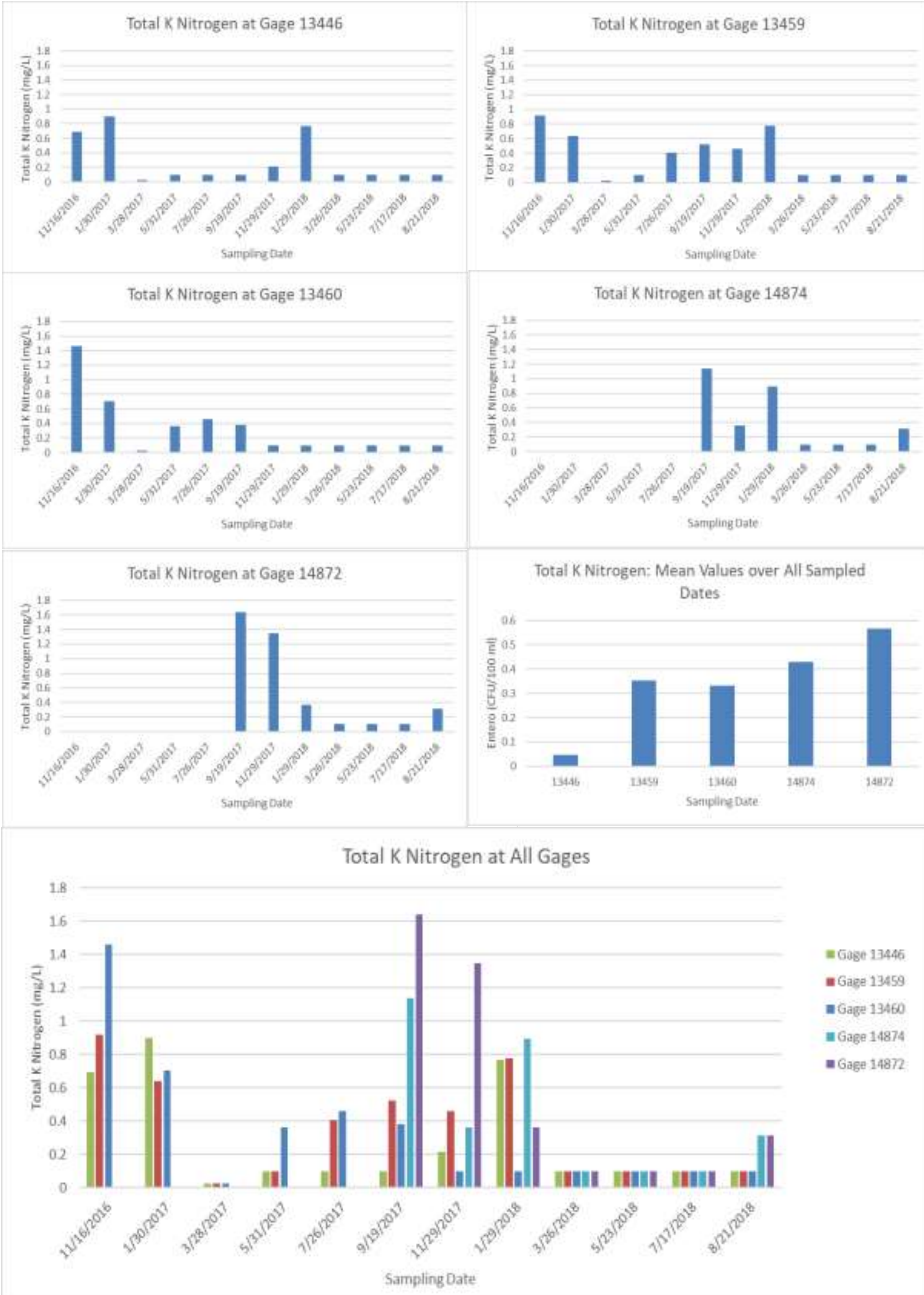


Figure 4-10: Total Kjelhdahl Nitrogen Data for Five Sampling Stations (including Mean Values for each Station and a Combined Station Graph for Comparison Purposes).

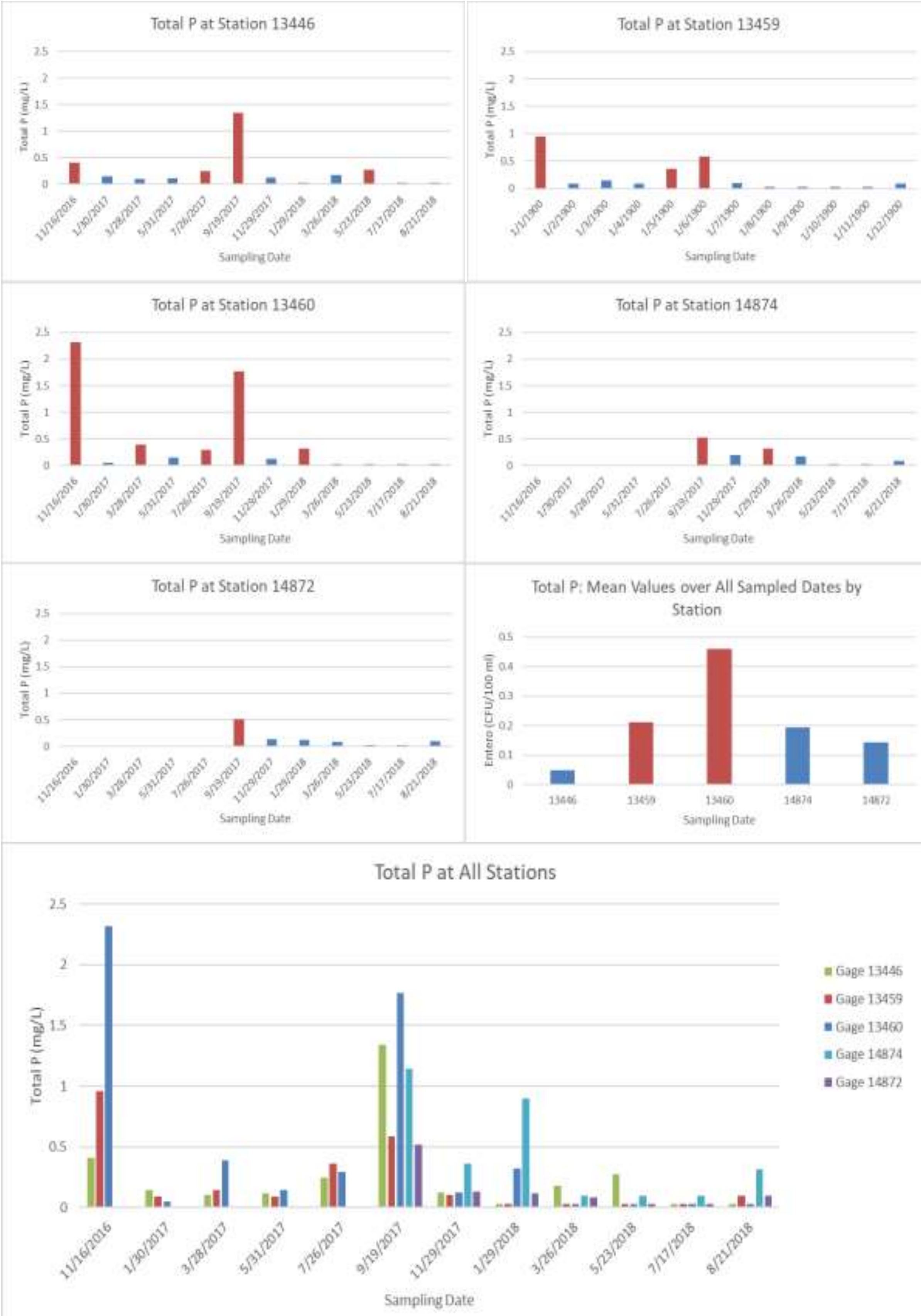


Figure 4-11: Total Phosphorous Data for Five Sampling Stations (including Mean Values for each Station and a Combined Station Graph for Comparison Purposes).

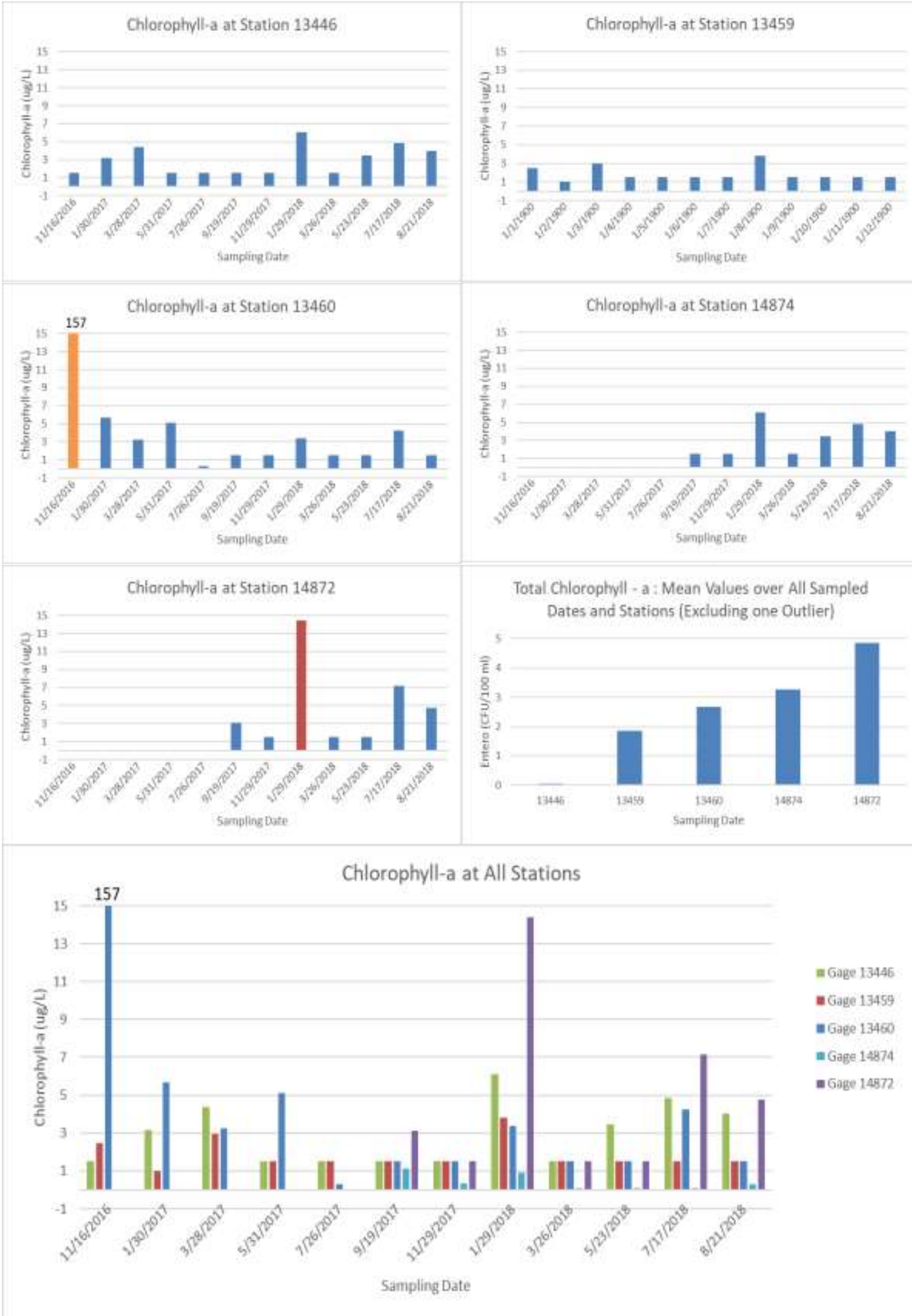


Figure 4-12: Chlorophyll-a Data for Five Sampling Stations (including Mean Values for each Station and a Combined Station Graph for Comparison Purposes).

4.4 SAN MARTIN LAKE AND DRAINAGE NETWORK SAMPLING DATA

Limited research of San Martin Lake and its drainage network was available. However, three studies that included water quality sampling were identified. They are summarized below.

4.4.1 San Martin Lake Studies

DeYoe et al., (2016) conducted 24-hour flow monitoring and nutrient sampling at a site upstream of Little San Martin Lake (Figure 4-13). This study was designed to estimate nutrient loading contributions from four ungaged subwatersheds in south Texas including San Martin Lake subwatershed. Sampling was done from June 2014 to November 2015. Results from the San Martin Lake site (POB north) for the period June 18 – 22 in 2014 are presented here. Daily tidal influence is observed for approximately 6 hours each day (Figure 4-14). Nutrient sampling over a portion of this period also shows higher nitrate concentrations and daily fluctuations than ammonia and phosphate during the same period (Figure 4-16). One notable feature of a November 2014 sample date for this site was that organic nitrogen made up a significant % of the total nitrogen ranging from 4 to 97% with an average of 34.2%.

Rogers (2018) conducted monthly sampling of seven sites from Little San Martin Lake to the outlet of San Martin Lake at the Ship Channel from August 2012 to July 2013 (Figure 4-18). Each site chosen was along a central transect where the greatest tidal flow and water depth occurred. The following data was acquired during the study: Temperature, Conductivity, Dissolved Oxygen, pH, Salinity, Chlorophyll-a, Ammonia, Nitrate-Nitrite, Dissolved Phosphate, and water depth. Sites were sampled close to high tide to ensure accessibility by boat. Little San Martin Lake was not accessible by boat due to shallow conditions. Water depths in the estuary vary widely with tides and depths at sampling locations ranged from <0.1m to >2.5m. The salinity values decreases with increasing distance from the Ship Channel as is to be expected in an estuary (Figure 4-17). The site closest to Little San Martin Lake had salinity ranges from 5.3 to 21.6 and an average of 13.33 ppt. It was usually brackish but sometimes was fresh. The nutrient values showed a generally increasing trend from the mouth of the Ship Channel with the highest values at the site next to Little San Martin Lake (Figure 4.18). This is indicative of nutrient loadings entering the system from drainage flows from the west. The study notes "Evidence of green algal blooms were observed on several sampling dates in Little San Martin Lake as there were bright green algal mats floating in the water." Rogers (2018) also notes that a large oyster bed in the middle of San Martin Lake may be filtering out seston and so indirectly reducing nutrient levels of outgoing water. Much higher nutrient values were observed on the western side of the oyster bed than the eastern side of the oyster bed.

San Martin Lake appears to be a very important estuary in the LLM/BSC Watershed. It is unknown how much freshwater makes it out of the lake system into the Ship Channel. The water quality in the Ship Channel at the outlet of San Martin Lake does not show lower salinities or higher pollutant concentrations indicating freshwater inflow. Sampling of the San Martin Lake system is crucial to understand pollutant loadings, and required to develop an EPA approvable nine-element WPP. Collecting flow data and routine water quality sampling is critical to develop the WPP.

Figure 4-13: San Martin Lake system sampling sites from previous research (DeYoe et al 2016) (Rogers 2018)

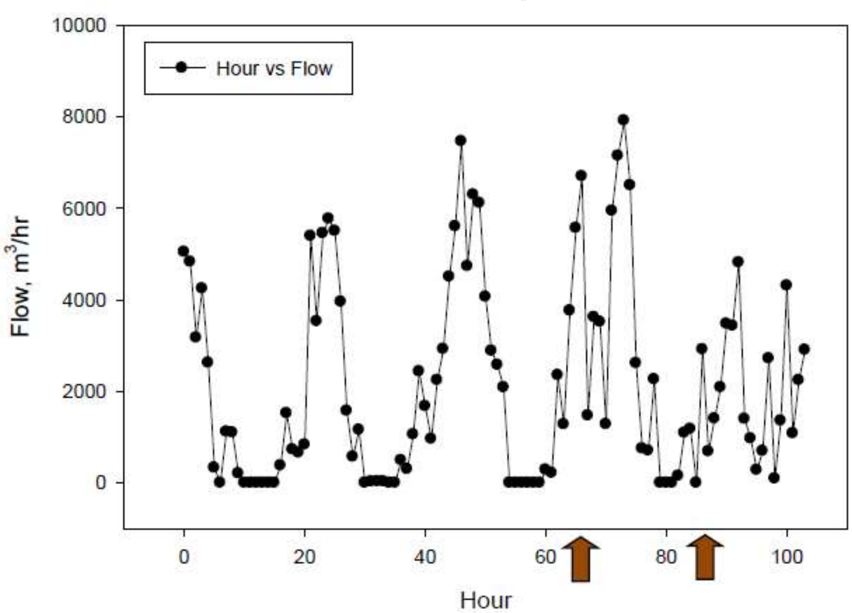


Figure 4-14: Hydrograph for POB north site 18-22 June 2014 baseline period. Arrows indicate start and end of monitoring. (DeYoe et al., 2016)

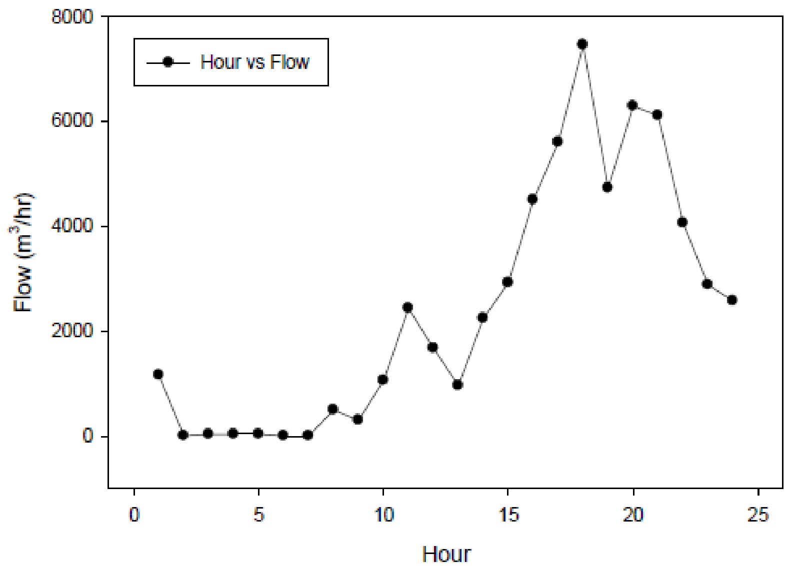


Figure 4-15: Hydrograph for POB north site June 2014 baseline sampling period (DeYoe et al 2016)

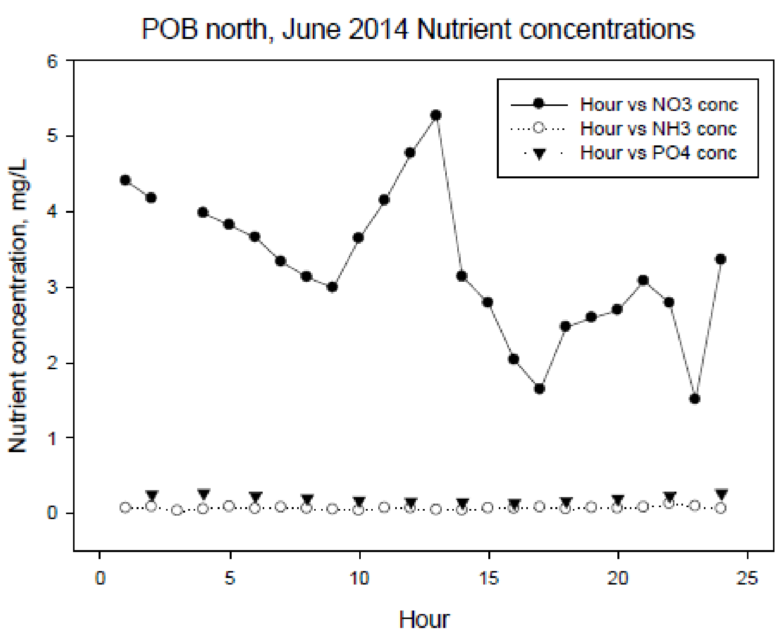


Figure 4-16: POB north site nutrient concentration during June 2014 sampling period (Deyoe et al 2016)

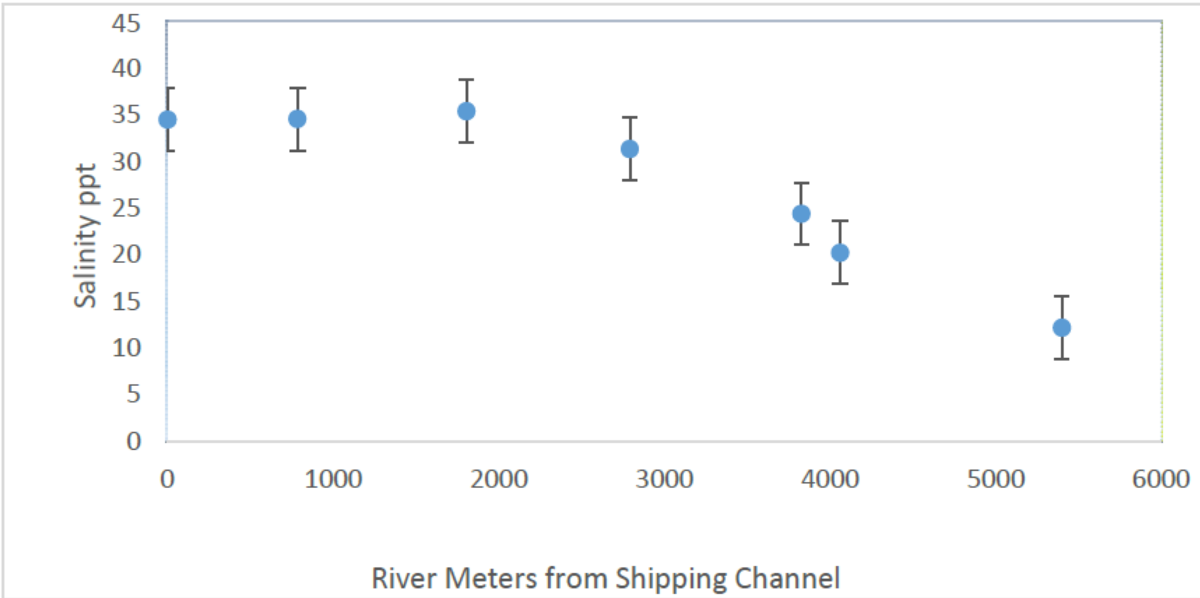


Figure 4-17: Average salinity and ranges over one year at the 7 sampling stations (Rogers 2018).

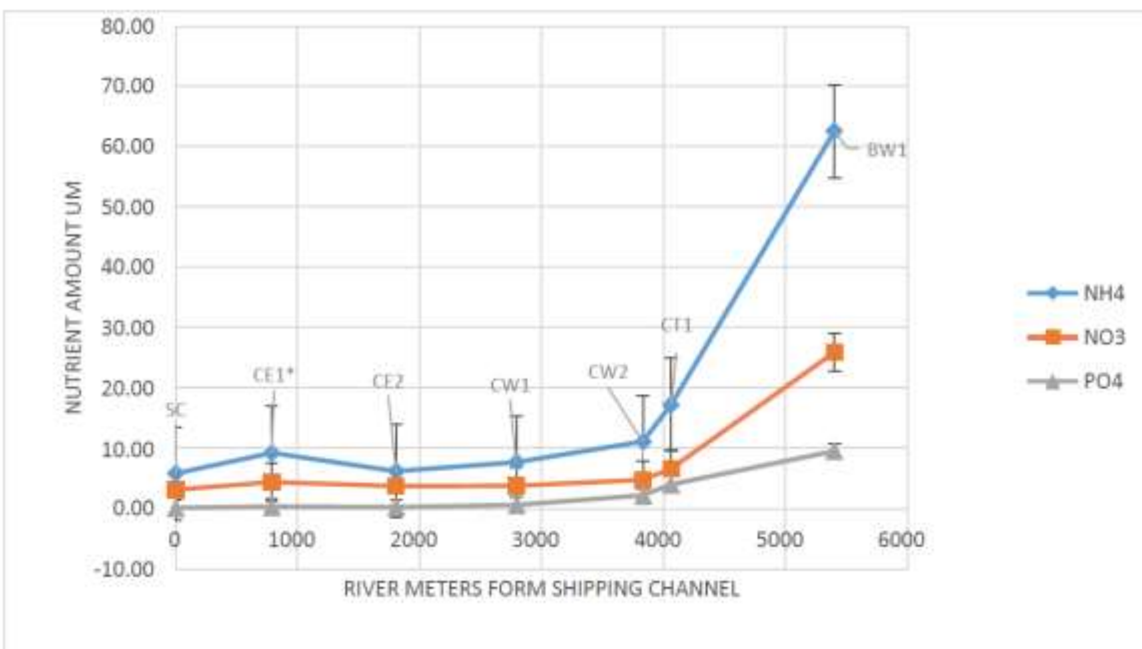


Figure 4-18: Sample averages for ammonia, nitrate-nitrite and phosphate in San Martin Lake. *At CE1 one data point was omitted due to abnormally high value (Rogers 2018).

4.4.2 Desalination Impact on water quality study

<Add short intro on GW desal in Valley>

Gamboa and Clapp (2013) conducted sampling of DO, temperature, conductivity, pH, dissolved total phosphorus, and ortho-phosphorus, and dissolved total arsenic in summer of 2006 and again in spring of 2007. There were five events in summer of 2006 on June 8, July 10, July 24, July 31, and August 28 and five in the spring of 2007 on March 10, March 17, March 23, March 31, and Grab samples were taken at 14 sites in 2006 and 12 sites in 2007, including seven of the previous sites and 5 new sites at San Martin Lake and Little Laguna Madre (see Figure 4-19). Results of the sampling is included in Figures 4-20 through 4-25.

The SRWA reverse osmosis plant brackish effluent has a NPDES permit limit for TDS of 16,704mg/L. The average TDS discharge measured during the 2006 and 2007 sampling events was 8,848 mg/L and 8,702 mg/L. There was an observed increase in TDS in the drainage ditches downstream of the plant compared to water in the drainage ditches upstream. However, the receiving water bodies downstream (San Martin Lake, Brownsville Ship Channel, and Bahia Grande) have much higher salinities due to naturally occurring saltwater inundation from the Gulf of Mexico. The study concluded that the increased flow in the drainage ditch provided a diluting effect on the TDS for the eventual receiving water bodies. The plant effluent did contain high total phosphorus levels. This was were primarily due to the use of a proprietary organo-phosphonate anti-scalant used in the RO pretreatment process. All downstream ditch total phosphorus concentrations were significantly higher (Gamboa and Clapp 2013).

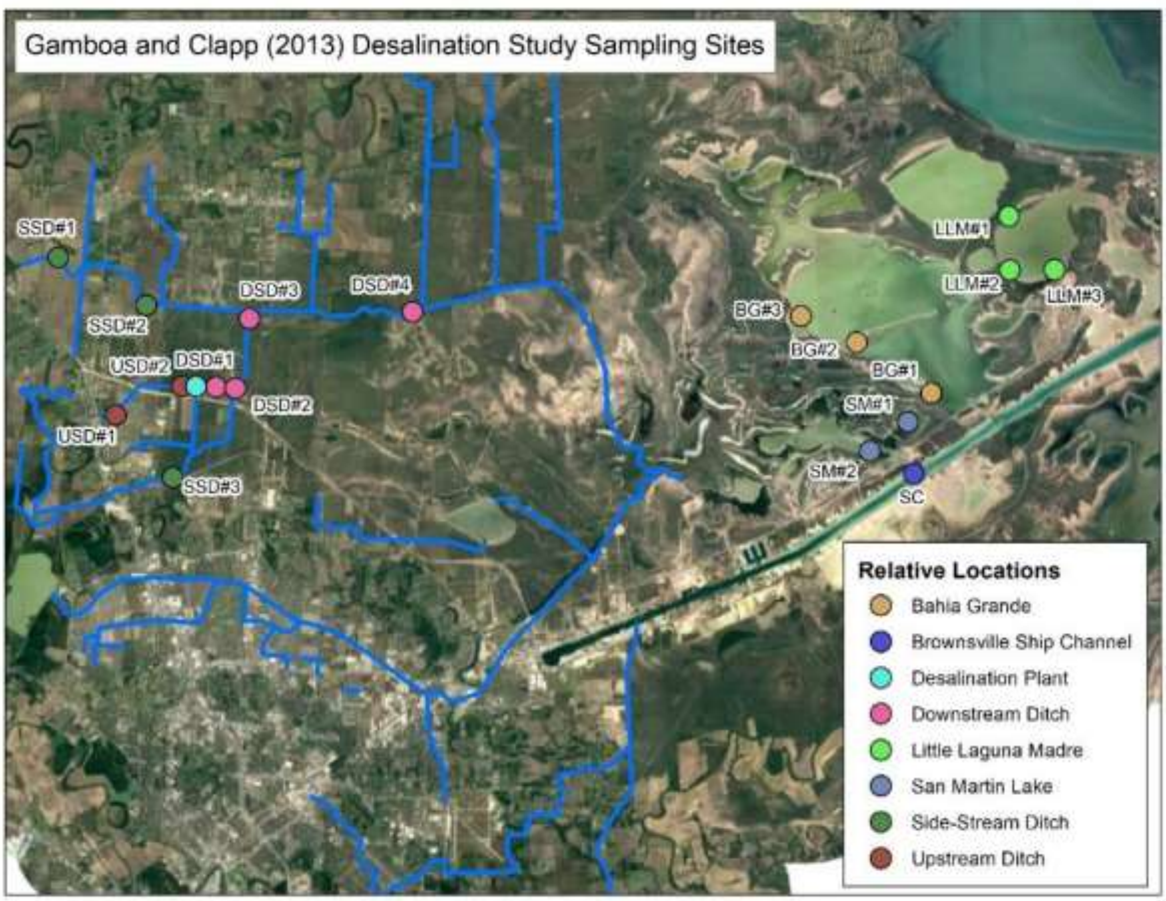


Figure 4-19: Relative locations of sampling sites for Summer of 2006 and Spring of 2007 (Gamboa and Clapp 2013)

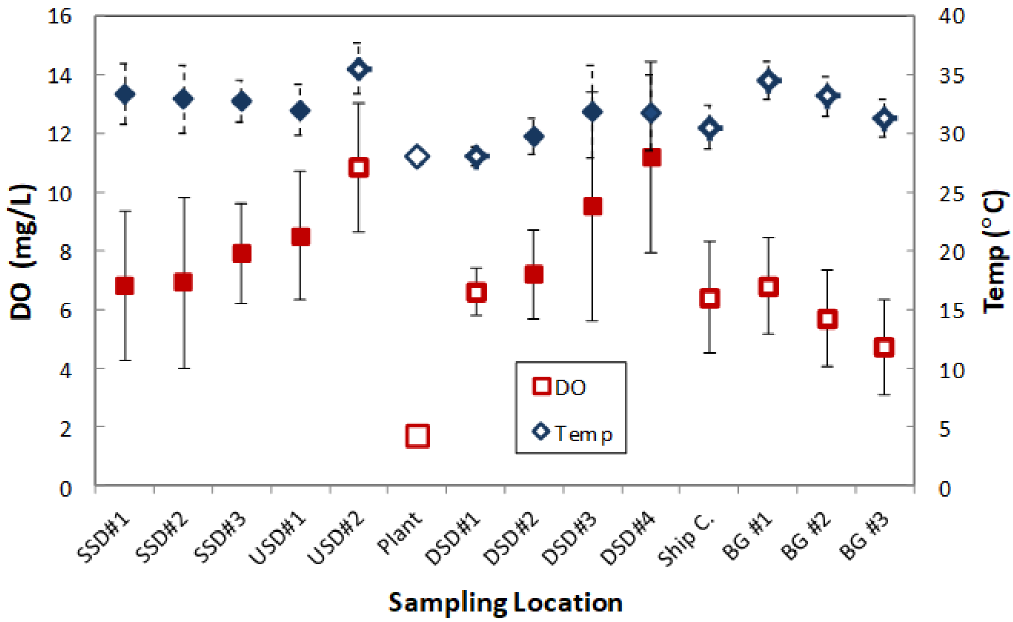


Figure 4-20: Average DO concentrations and temperatures for sites sampled in summer 2006. Locations with open symbols were also sampled the following spring. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

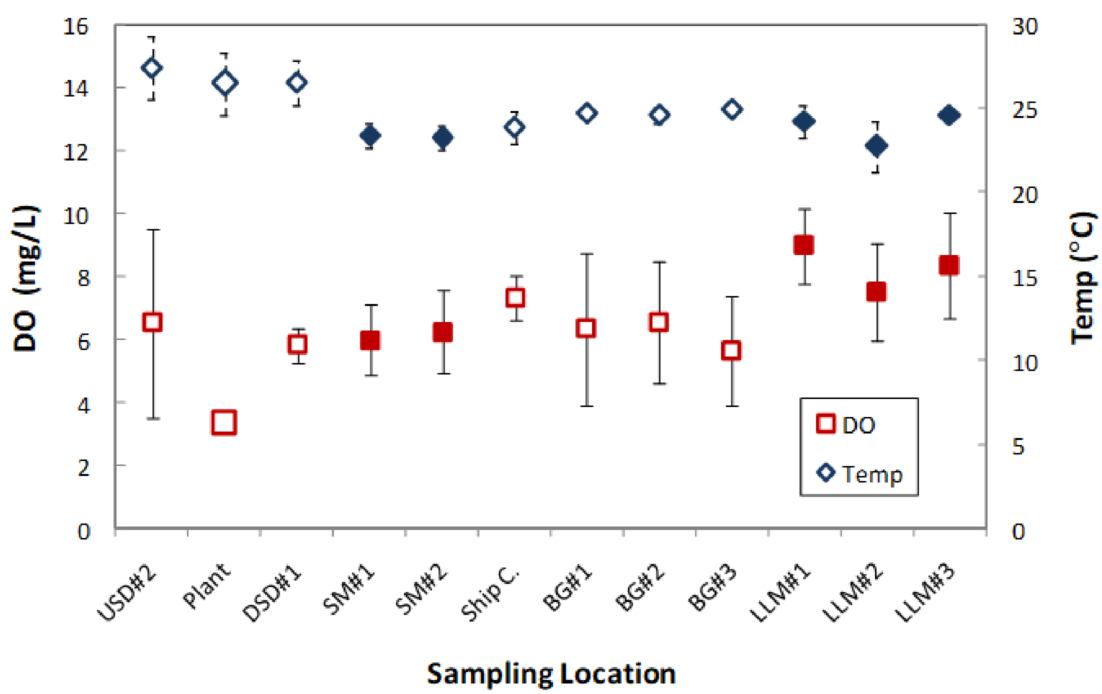


Figure 4-21: Average DO concentrations and temperatures for sites sampled in spring 2007. Locations with open symbols were also sampled the previous summer. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

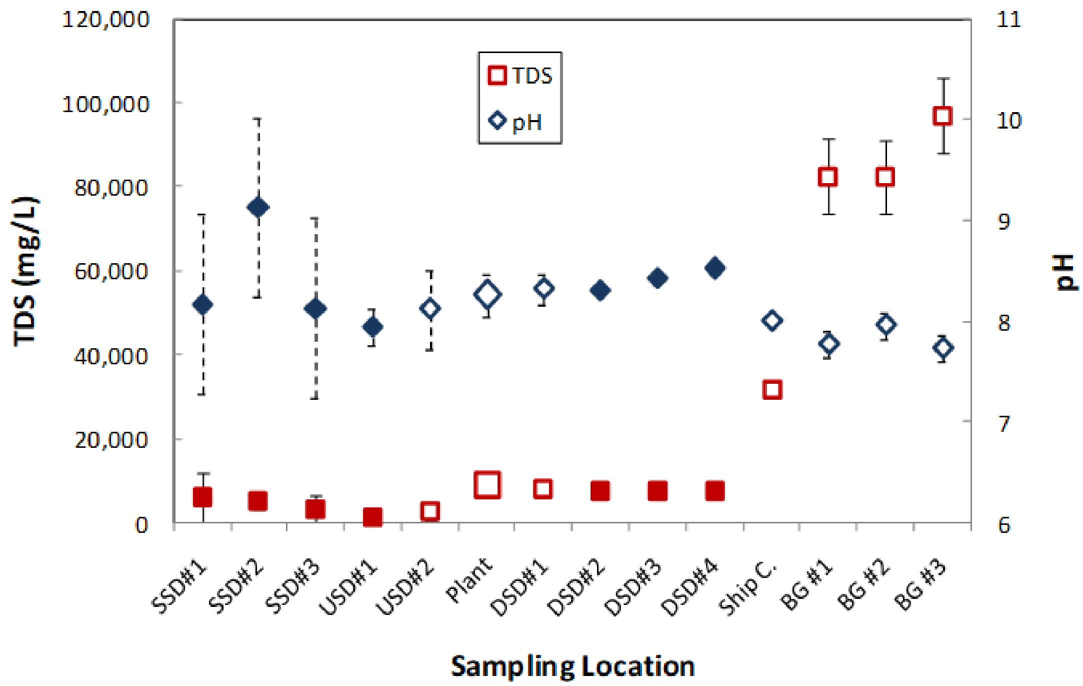


Figure 4-22: Average TDS and Ph values for sites sampled in summer of 2006. Locations with open symbols were also sampled the following spring. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

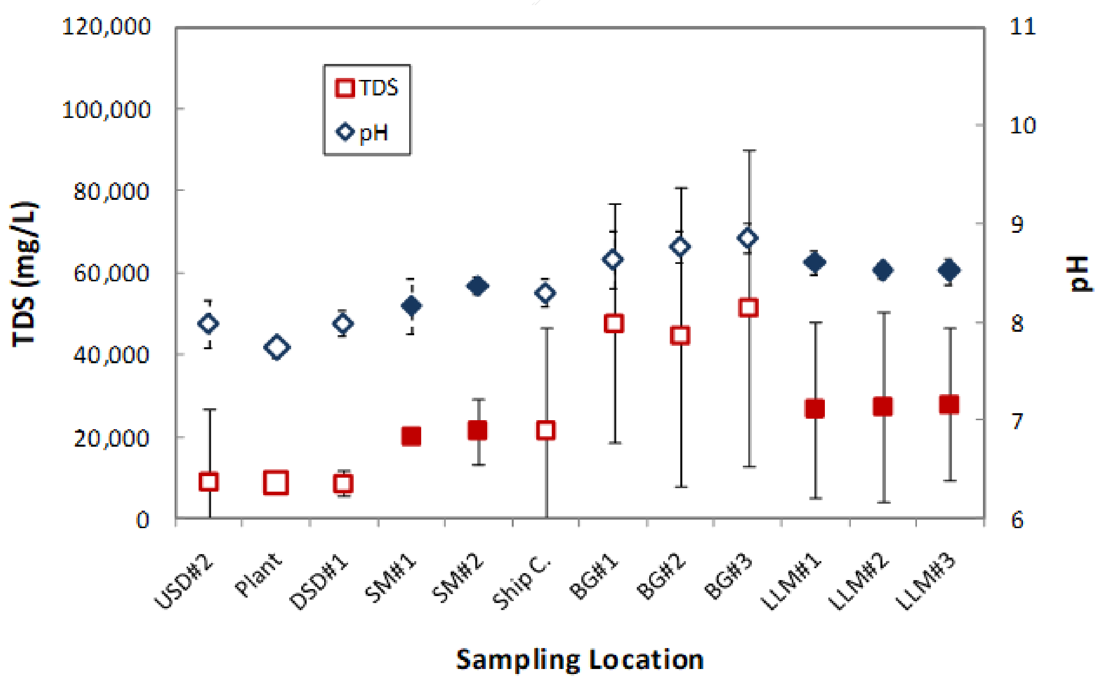


Figure 4-23: Average TDS and Ph values for sites sampled in spring of 2007. Locations with open symbols were also sampled the previous summer. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

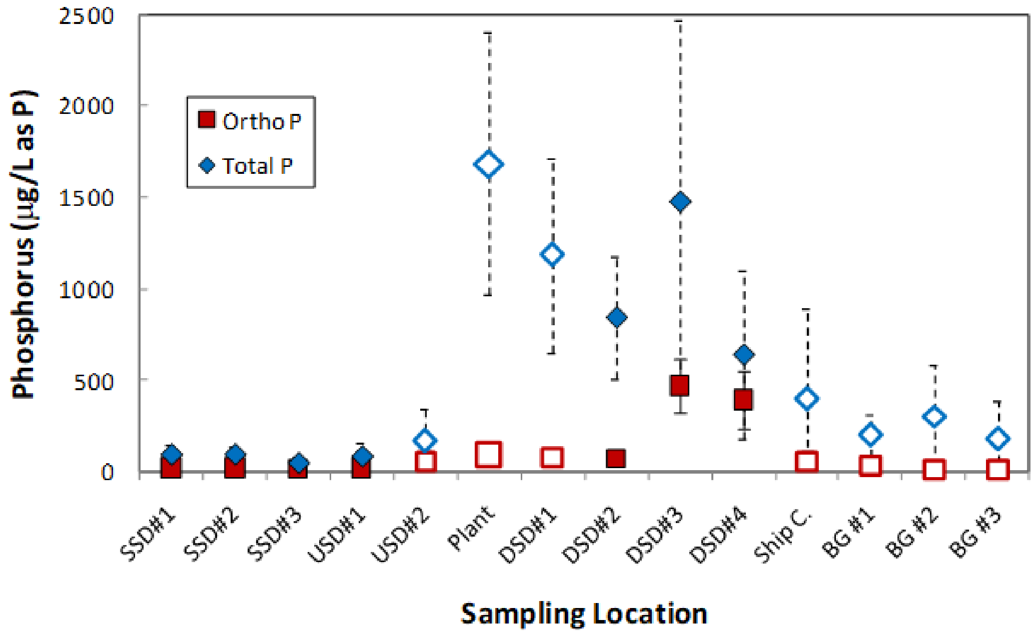


Figure 4-24: Average dissolved total and ortho-phosphorus at sites sampled in summer of 2006. Locations with open symbols were also sampled the following spring. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

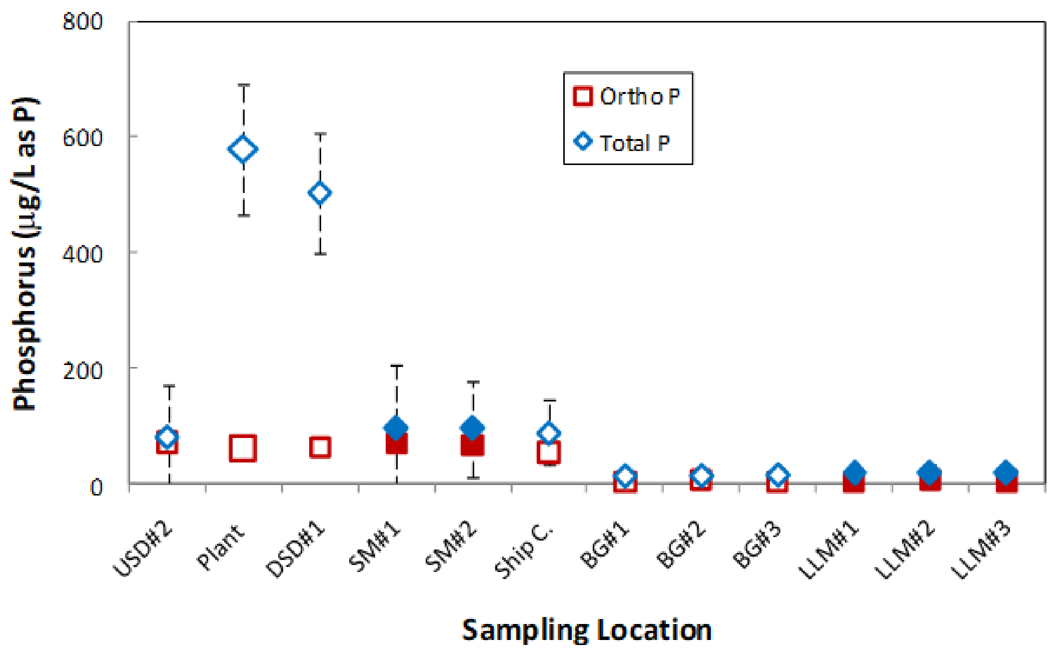


Figure 4-25: Average dissolved total and ortho-phosphorus at sites sampled in spring of 2007. Locations with open symbols were also sampled the previous summer. Error bars are 95% confidence intervals. (Gamboa and Clapp 2013)

4.5 SOUTHMOST DRAIN SAMPLING DATA

There is limited data for the Southmost drain. DeYoe et al., (2016) conducted 24-hour flow monitoring and nutrient sampling at a site on the Southmost Drain about 200 m upstream of its outlet into the Brownsville Ship Channel (Figure 4-26). Data was captured for a rainfall event (4.11in.) from September 12-14, 2014. Salinity, dissolved phosphate, nitrate-nitrite, and ammonia samples were collected each hour for 24-hours (Figure 4-27). For the first hour, salinity was about 35ppt and then decreased below 5ppt by hour 3 and remained below 5ppt for the remainder of the sampling. Nitrate-nitrite concentrations increased significantly from hours 5-18 of the event and then declined to background levels. Low salinity during sampling (below 5ppt) indicates that much of the stormwater reached the Ship Channel outfall. High salinity during the first 2 hours of sampling indicates that the initiation of the runoff event was captured. Another rainfall event of 1.7in from August 30 – September 1, 2014 was sampled and flow was measured over a 48-hour period (Figure 4-28). The flow was measured close to 0 at the beginning of the event showing likely tidal influence and then peaked at greater than 4,000m^3/hr. It is important to note that throughout the 48 hours it appears that there was always flow towards Ship Channel even during high tides. This indicates that the Southmost Drain may contribute more freshwater to Ship Channel than San Martin Lake. Further research is needed to confirm this.

Figure 4-26: Southmost Drain sampling site in Brownsville subwatershed (DeYoe et al 2016)

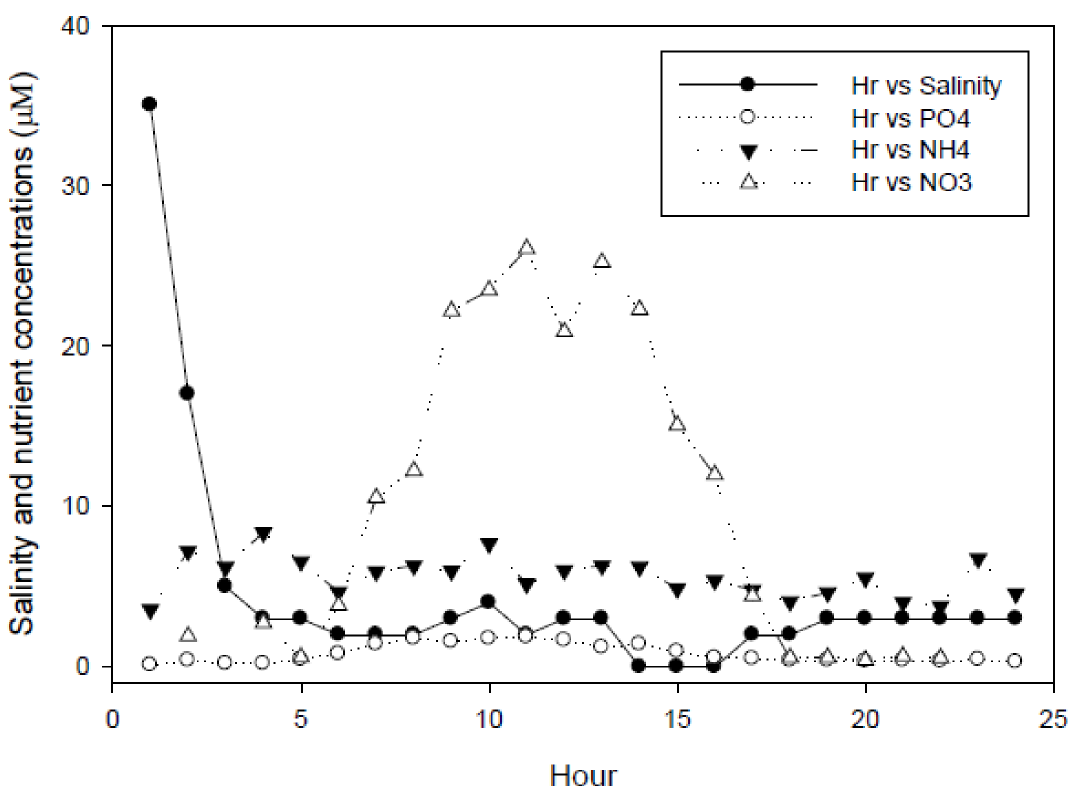


Figure 4-27: Southmost drain site salinity and nutrient levels for September 2014 event. Rainfall from September 12 – 14 was 4.11in. (Deyoe et al 2016)

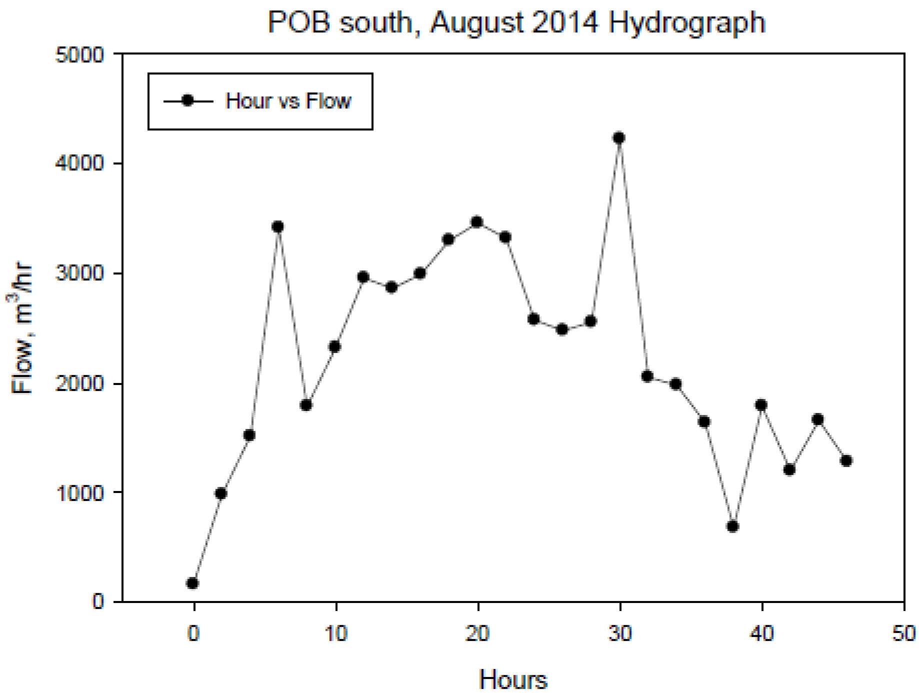


Figure 4-28: Hydrograph for Southmost Drain site for August 2014 rainfall event. Rainfall was 1.7in from August 30 – September 1 2014. (Deyoe et al 2016)

4.6 Overall Water Quality ISSUES and Concerns Discussion

<Add overview of main conclusions.>

- Ship Channel is showing ok bacteria levels. Maybe it isn't impaired?
- San Martin Lake is a major receiving water body that is understudied.
- San Martin Lake may have nutrient and algal bloom issues and should be a focus of the WPP
- Unsure of how much freshwater inflow is occurring. Ship Channel doesn't show much stratification like Arroyo Colorado

4.7 Additional Data Needed for Developing a 9-element WPP

<Section Under Construction. Add more description, etc >

- No daily flow measurements anywhere in watershed
- No bacteria samples since 2008 for coordinated monitoring
- No long-term sampling of San Martin Lake
- No long-term sampling of drainage network of the receiving water bodies
- Unsure how much freshwater flow actually making it out of San Martin Lake and into Brownsville Ship Channel

- Flow and sampling at same time needed for load duration curves at diches and San Martin Lake

5 WATERSHED PARTNERSHIP AND COMMUNITY ENGAGEMENT

5.1 PARTNERSHIP FORMATION

<Add summary of initial Partnership efforts and voting for WPP. PPP was formed. Steering Committee List and Work Groups.

5.2 COMMUNITY ENGAGEMENT

<Add summary of and list of meetings presented study at. Website>

- 6.1.1 Public Participation Plan (PPP) – TWRI worked with the TCEQ PM, project partners and stakeholders to develop a PPP prior to initial Stakeholder Group development. The PPP provided an outline of the goals of future meetings, topics, and an estimated timeline that provided an outline for project personnel to follow as the watershed planning and implementation process was conducted. The PPP was approved by the TCEQ and finalized on 2/25/15 and presented to stakeholders for feedback.

- 6.1.2 Facilitate and Coordinate Meetings – The TWRI PM worked to facilitate public participation and stakeholder involvement in the Characterization and Watershed Planning Process by coordination and hosting 8 meetings during the project period on these dates; 2/26/15, 6/25/15, 1/21/16, 4/14/16, 6/30/16, 7/27/16, 8/3/16 and 8/12/16. Meeting summaries were posted on the Arroyo Colorado website.

- 6.1.3 Stakeholder Group Activities – The TWRI PM and project partners implemented the PPP by establishing a stakeholder group and facilitating and coordinating their activities, which included: continued facilitation of the Stakeholder Group; Hosting and facilitating meetings; Leading the Stakeholder Groups in identifying sources of pollution in the watershed, input on re-naming watershed from Brownsville Resaca to Lower Laguna Madre/Brownsville Ship Channel watershed, input on sub-watershed boundaries, input on water quality sample locations and the development of watershed characterization report; Leading the stakeholder group in developing a grant application for Phase II.

- 6.1.4 Dissemination of Project Information – The TWRI PM and project partners conducted public outreach in accordance with the PPP to inform the public about the project and its status, sources of pollution, and how the public/stakeholders can address water quality issues.

  Activities included:

  - Hosting a project webpage on the Arroyo Colorado website;
  - Posting the PPP on the webpage
  - Posting all maps and presentations on the webpage
  - Posting all Quarterly Progress Reports on webpage

- Communicating via media sources; email invitations to stakeholders announcing meetings, 2 articles on the project and Lead P.I., Jude Benavides, Facebook updates on meeting dates/project activities
- The TWRI PM, UTRGV PM & TCEQ PM developed presentations on the project and presented them at the Stormwater Task Force Conference in 2014, 2015, 2016 & 2017.

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Appendix A: Datasets

- LiDAR data sources
- Flood Studies (Balli 1976; Hogan and Razor; Rust, Litchlighter, Jameson; Ambiotec 2005 and 2009;
- Water Quality Studies (USACE – Resaca Restoration and Habitat model)
- More……

Appendix B: SWQMIS Historical Water Quality Data Analysis

The entire historical water quality document completed by TIAER will be made available via this appendix and is part of the deliverables of this report.